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THE BRITISH JOURNAL OF METALS

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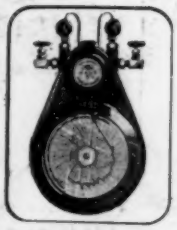

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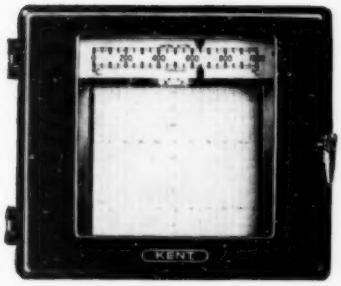

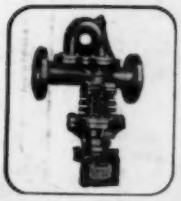

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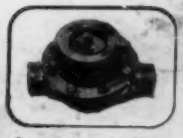

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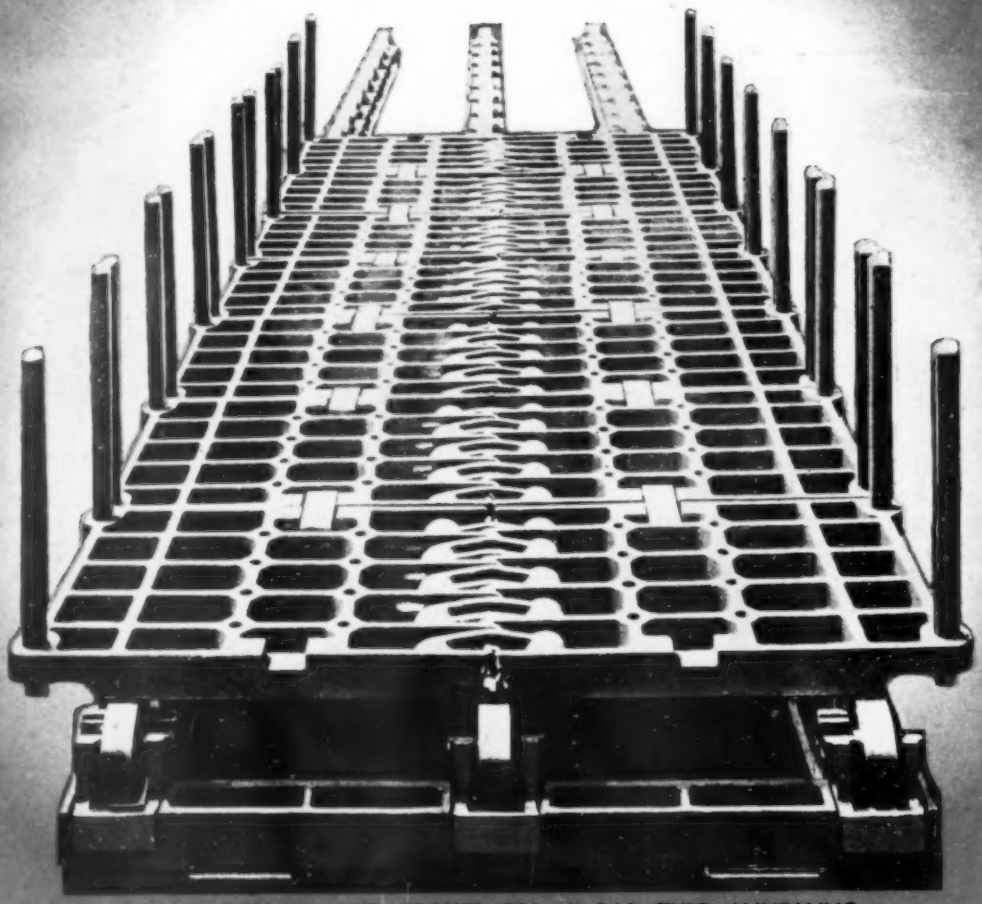

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The British Journal of Metals

(INCORPORATING THE METALLURGICAL ENGINEER)

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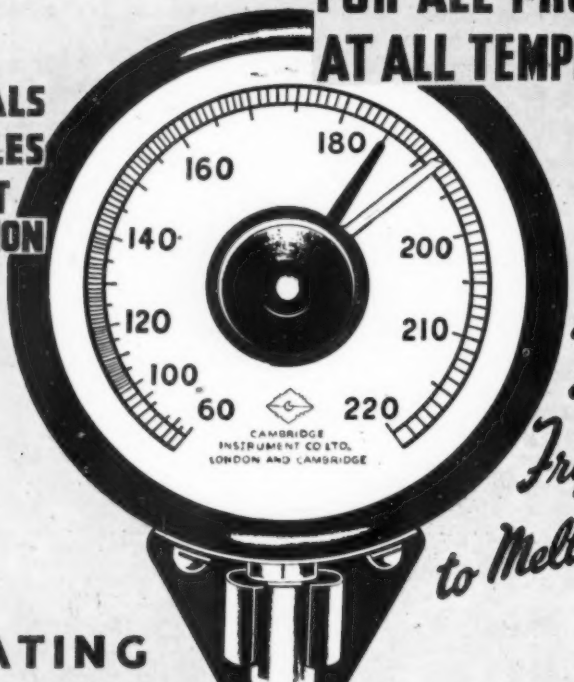

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METALLURGIA

THE BRITISH JOURNAL OF METALS.

INCORPORATING "THE METALLURGICAL ENGINEER."

SEPTEMBER, 1947 Vol. XXXVI No. 215

Economy on Research and Development in the United States

THE impression that there are unlimited funds for research in the United States is not always well founded. Several recent drastic cuts ordered by Congress in the 1948 appropriations to various departments indicate, indeed, a certain urge towards economy —even in research and development. For example, next year's appropriation to the Bureau of Mines has suffered a 33% reduction, that is to $10·5 million, from $16·8 in 1947. As a result, it is said that many investigations vital to future welfare and security, so largely based on metals and minerals, will have to be curtailed or cancelled. One of these is development of methods for the more effective use of low-grade ores; and others relate to production of sponge iron, and to studies in connection with zirconium, cobalt, chromium and manganese. Many pilot plants in these and other branches of the Bureau's work will have to be closed; probably including the sponge iron plant at Laramie (Wyoming), said to be the only U.S. domestic source of sponge iron, and the zirconium plant at Albany. Work on titanium alloys required in jet aircraft construction will no doubt be curtailed. Other plants to be closed include lignite gasification at Grand Forks (N.D.), bauxite beneficiation mill at Bauxite (Ark.), and the electrothermic magnesium plant at Pullman, Washington.

Surveys and development of domestic mineral resources will also suffer, and studies in the location and development of critical minerals, which are at present mainly imported and would be in short supply in an emergency, will have to be strictly limited. At present, with fifty metals and minerals on the strategic and critical list, the Bureau has to abandon an inventory of mineral resources for the national stockpile programme. The cut will also render impossible the planned investigation of radio-active mineral deposits, and curtail the study of economic aspects of mineral industries. Congress expressed the view, in regard to these latter statistics, that if they are of value to the industries concerned the work should be done by and at the cost of those interested who are likely to benefit from the information.

Substantial reductions have also been made in the appropriations for 1948 to the Department of Commerce —i.e., 33%, from $287 million to $181 million; and to the Bureau of Standards, from $10·6 million to $7·4. Even the Patent Office, despite heavy and continued increase in work, has been reduced by $0·5 million. The Office of Technical Service (O.T.S.) for getting information on German industry is apparently to be abolished, on the ground, *inter alia*, that much of the information was available to anyone interested enough to take the trouble to translate German magazines and other publications. Evidently the view in U.S. Government circles is that, in the present condition of world political trends, it is more than ever necessary to encourage a spirit of sturdy independence and self-help with a minimum of state support or interference. American industry must not expect too much from state finance. No doubt the departments concerned could make a more or less effective rejoinder to this political philosophy.

So far as the Bureau of Mines has been concerned in the past with strategic minerals, this part of their work has been transferred apparently to a new department: the Bureau of Federal Supply (Strategic and Critical Materials Division) which has recently invited tenders for maximum offers of manganese ore for delivery during each of the next four years beginning July 1st; for the U.S. Government has now decided to raise the target for its manganese ore stockpile from 3,000,000 to 5,000,000 tons. It is stipulated that, in submitting tenders for this ore it must first have been offered to and declined by three commercial manufacturing concerns. In view of the activity of the American steel industry it seems doubtful if there will be any considerable response to this invitation to tender. Present stocks accumulated during the war years are mostly low grade and probably do not exceed 1,200,000 tons.

World supplies of ferro-manganese over 48% have long been insufficient and are augmented by mixing in lower grades. Russia may again come forward as a source of supply, though her prices have been too high; and the Gold Coast, too, where output increased by 50% during the war, may soon overcome some of the worst of the internal transport difficulties which have lately hampered export.

Although the urge to economy indicated in the foregoing notes refers more particularly to the work of the Bureau of Mines, it may be regarded as the present policy of Congress to relieve itself of the responsibility, at least to an appreciable extent, of research and development work. The feeling in the United States seems to be increasing that competitive research is more desirable, whether it is done in firm's own laboratories, in the Colleges and Universities, or in private co-operative research laboratories. This is in distinct contrast to research and development work in Britain where praiseworthy efforts to direct attention, in both political and business circles, to the all-important fostering and extension of industrial research are meeting with considerable success. The Government appreciates the need for increased research in this country and has supported its policy with additional financial backing. Especially is this true of the research associations which are receiving increased grants from the Department of Scientific and Industrial Research, and as will be noted in the reviews of the work of some of these associations, published elsewhere in this issue, they are serving admirably the interests of the industries they embrace and are a national asset.

The Road to Recovery

JUST as we were on the press with this issue a plan to bring relief in Britain's economic crisis was propounded by Sir Stafford Cripps in a speech to representatives of industry. After reviewing the circumstances which have led up to her present economic condition, he stressed the need for greater productivity to raise the volume and value of exports. We had now reached the situation, he said, where we must make the most urgent and comprehensive effort to balance our overseas payments as rapidly as possible. We might be able to get further temporary assistance from the United States under the Marshall Plan or in some other way, but we cannot count upon this, we must therefore proceed upon the basis that we must ourselves balance our own accounts. To do this we must adjust our standards of living and conditions of work wherever it is necessary. We are determined to maintain our economic independence and thus enable our country to continue to make its own independent contribution to the working out of international policies. We do not wish to be tied by economic strings to the political policies of other countries, however, friendly they may be.

It is difficult to assess with great accuracy the degree of unbalance which is likely to exist in Britain's future overseas payments. The unbalance of her dollar account is of course the most obvious and critical, but Sir Stafford gave a warning that her total overseas payments are also out of balance.

There is nothing new in Sir Stafford's scheme. He emphasises that persistent hard work is our only means of salvation and that it must be directed primarily to increased exports. We have to increase exports by £31 million a month. Probably the most important part of the scheme is the fact that precise figures are given, industry by industry, of the percentage expansion required to achieve target objectives. These are designed to increase exports ultimately by 60 per cent. in volume of the 1938 level. This is no mean task, particularly as overseas demand is not stable, but the targets provide a definite objective which the industries concerned will strive to attain. It should be noted that this increase in exports is not to balance the imports we need to maintain our standard of living as it was in June last, but to balance the reduced imports after the cuts so far imposed. Thus, even the achievement of the targets will not reduce the need for austerity ; exports must be increased much further before we can reach the level of imports that will enable us to regain our standard of living of 1938, let alone improve upon it.

It seems apparent, however, that the extra volume of exports represented by £31 million a month is the minimum to be achieved at the earliest moment possible. Otherwise we shall be unable to supply ourselves with emough food and raw materials to keep the production machine going. We must export that quantity; what is left after reaching the targets may be directed to the home market. To what extent we can buy food and raw materials outside the dollar area remains to be seen, but we shall have to earn all the dollars we can both directly by our own efforts and through other countries in the sterling group. Indeed, if we are to achieve the figures given, we shall have to make a considerable increase in the sale of our goods in hard currency countries, because many of our exports will go to countries with inconvertible currencies.

The fact that Sir Stafford has indicated his support for an Empire customs union, accompanied by intensive colonial development, is of great importance. Britain should be able to rely upon a more effective development of the resources of the Commonwealth and Empire. Trading within the group is easier and would be improved if a customs union could be worked out and approved. Mutual trading within the Commonwealth and Empire is freer and less likely to be interfered with by external forces which we cannot control ; it is truly multilateral so far as it is based on sterling and therefore easier to increase than our trade with other countries. Just as the United States or Soviet Russia have found strength in the building up of extensive free markets within their own great territories, so we and the Dominions and Colonies might benefit from a similar free area throughout the British Commonwealth and Empire.

The efforts to obtain a balance will involve substantial cuts, the most outstanding being a cut in capital investment of the order of £200 million a year. Apparently this will have to be made in all non-essential development projects, in the building of offices and of houses, in the improvement and extension of factories not producing for the export trade, and in the provision of schools. The cut is surely not intended to apply in the modernisation of obsolete plant and machinery needed in the export drive. Nor will it apply to the hydro-electric schemes which have been approved, to the provision of more agricultural machinery, drainage and water schemes, improvements to our transport system, all of which will be necessary to facilitate work for exports. It seems that every scheme involving capital expenditure will be carefully scrutinised. Substantial cuts in building and civil engineering work will mean the cessation of many important projects at present in progress, except in special cases or in those areas where new factories are essential to provide employment for those at present unemployed.

On the question of organisation Sir Stafford discussed materials and labour. The most important materials are coal and steel. Coal is not only vital to the production programme but a measure of export to Europe is also vital to the rehabilitation of the eastern hemisphere and the reduction of its dependence upon the western. However much the supplies of coal fall short of our total requirements it is vital that sufficient should be provided for the main export industries to enable them to achieve their task, even if this were to mean that we had to go short elsewhere. Arrangements are being made for industry to get 24¼ million tons during the winter six months. The extra steel needed for exports will be obtained mainly from savings from our capital investments programme at home. Where there is a choice, it is intended to manufacture articles for export which show the highest conversion value, so as to economise these two vital factors in our production. With the estimated production of 14 million tons of steel in the next steel year we should be able, with the economies in home use, to find all we want for the export programme, though the steel industry will need to be flexible in producing the qualities needed.

Industry is called upon to shoulder a formidable task, but as stated by Sir Stafford, " faith in our own future coupled with those high standards of commercial honesty and industrial integrity which built the foundations of our past prosperity can inspire us to these fresh efforts that are now called for."

Creep Rate of Various Industrial Leads*

By J. Neill Greenwood, D.Sc., M.Met.E.† and J. H. Cole, M.Sc.‡

Investigations have shown that traces of some elements were very effective in changing the creep rate of lead, some increasing and others decreasing the rate; the influence was not necessarily progressive. Industrial leads from various sources and refined by different processes have been examined to see whether the composition differences gave results in agreement with those obtained from synthetic laboratory products, the results of which are given in this paper.

Introduction

In previous papers[1-5] the effects of small additions of various elements on the creep rate of Port Pirie lead have been studied. During the investigations it was found that traces of some elements were very effective in changing the creep rate of lead, some increasing and others decreasing the rate. Further, it was found that the influence of a given element was not necessarily progressive. In some cases (Cu and Bi), the first additions caused an increase in rate, whilst further additions reversed this tendency. The opposite effect has also been found (Ag), namely that the improvement with small additions was lost with further increase in concentration. Typical results are summarised in Table I.

TABLE I
COMPARISON OF RATE OF CREEP OF VARIOUS LEAD ALLOYS AT 20° C. STRESS 350 LB./SQ. IN. CONDITION ANNEALED 100° C. FOR 15 MINUTES

Addition Element	Times in days for 2% increase in length		
	0·01% added	0·05% added	0·10% added
Basis lead (U)	(250)	(250)	(250)
Mg*	1,460†	‡	—
Ca	1,400†	§	§
Cu	170	465	‖
Zn	610	1,050†	1,050†
Ag	510	480	390
Sb	165	220	180
Te	—	70	—
Bi	165	265	350

* Although magnesium markedly lowers the creep rate of lead, it is useless as an addition element as the alloys gradually disintegrate.
† Values estimated by extrapolation from 800 days.
‡ This alloy reached a constant length after stretching 1% in 250 days. It is, however, unstable.
§ Increased 0·02% in 800 days.
‖ Increased 0·25% in 800 days.

From this table it will be noted that the elements normally present in lead as impurities, namely, silver, antimony and bismuth do not greatly influence the creep rate when present up to 0·10%. Zinc, 0·05%, appears to reduce the creep rate of lead to about one-quarter, copper over 0·05%[3] to about one twenty-fifth and calcium 0·05% to one three-hundredth of the rate for "U" lead. The influence of calcium is therefore quite outstanding.

It followed as a matter of interest that industrial leads from various sources and refined by different processes should be examined, to see whether the composition differences gave results in agreement with those obtained on synthetic laboratory products. A further point of interest lay in the possibility of the presence of some unsuspected element giving results not in accordance with expectation. It can, however, be said at this stage that, using lead from six different ore bodies located in four continents, no unexpected results have been obtained.

The creep tests were carried out by methods previously described.

Materials Used

Ingots of several brands of industrial lead were purchased on the London market during 1936 and a description of these is given in Table II. Each ingot was analysed and the results are given in Table III.

TABLE II
ORIGIN AND REFINING PROCESS OF INDUSTRIAL LEADS

Mark	Source	Refining Process
1..	Australia	Continuous
2..	Australia	Continuous
3..	Australia	Parkes
4..	North America	Electrolytic (Betts)
5..	Burma	Parkes
6..	Burma	Parkes
7..	Europe	Pattinson
8..	Europe	Not known

TABLE III
ANALYSES OF LEADS USED*

Element %	1	2	3	4	5	6	7	8
Cu	0·0001	0·0002	0·0002	0·0005	0·0002	0·0002	0·0140	0·0006
Bi	0·0007	0·0023	0·0014	0·0011	0·0072	0·0493	0·0000	0·0125
Cd	0·0001	0·0001	0·0001	0·0001	0·0001	0·0001	nil	0·0002
Sn	nil	nil	nil	nil	nil	nil	nil	nil
Sb	0·0005	0·0042	0·0000	0·0021	0·0034	0·0029	0·0095	0·0003
As	nil	nil	0·0007	0·0002	0·0010	0·0000	0·0000	0·0000
Fe	0·0006	0·0007	0·0002	0·0007	0·0005	0·0004	0·0003	0·0006
Zn	0·0002	0·0005	0·0002	0·0004	0·0003	0·0004	0·0097	0·0004
S	0·0001	0·0004	0·0003	0·0004	0·0007	—	0·0056	0·0004
Ni	—	—	0·0000	0·0000	nil	0·0000	0·0014	0·0001
Ag	0·0000	0·0003	0·0003	0·0006	0·0004	0·0002	0·0040	0·0028
Co	—	—	0·0005	—	—	—	—	—
Total	0·0023	0·0087	0·0039	0·0061	0·0138	0·0535	0·0355	0·0179

* These analyses were carried out under the direction of Mr. P. F. Somerset in the laboratories of the Broken Hill Associated Smelters at Port Pirie.

Conditions of Test

The material for test was prepared in the laboratory in the usual way by rolling 6 in. × 1 in. × 1 in. ingots to strip $\frac{1}{8}$ in. thick by a standardised technique at a temperature of 20°–24° C. Each pass reduced the thickness by 0·028 in.

The strips were tested in two conditions (a) as rolled, (b) annealed 15 minutes at 100° C. This annealing was carried out in an air oven, the lead strips being placed flat on a cast iron surface plate (true to 0·001 in. over 9 in.). They were withdrawn by sliding on to a similar plate and allowed to cool without further handling. This annealing was done before the strips were cut to shape. As the shaping was done by careful cutting in

* Publication has been delayed by the war. The work was completed in 1941.
† Research Professor of Metallurgy, Baillieu Laboratory, University of Melbourne.
‡ Formerly research scholar, School of Technology, University of Melbourne, now Metallurgist Munitions Supply Labs., Maribyrnong.
1 J. Neill Greenwood and collaborators, *Proc. Aust. Inst. M. and Met.*, Nos. 95, 101, 104, 109, 111, 113.
2 J. Neill Greenwood and H. K. Worner, *Proc. Aust. Inst. M. and Met.*, No. 104 (1936).
3 J. Neill Greenwood and C. W. Orr, *Proc. Aust. Inst. M. and Met.*, No. 109 (1938).
4 J. Neill Greenwood and H. K. Worner, *J.I. Met.*, 64, 1939.
5 J. Neill Greenwood and C. W. Orr, *Proc. Aust. Inst. I.M.M.*, No. 113 (1939).

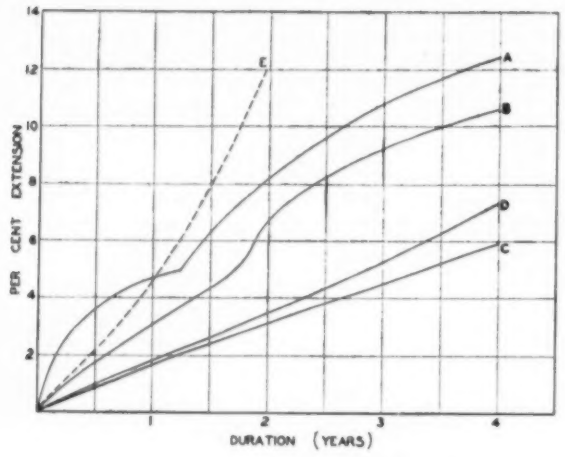

Fig. 1.—Typical creep curves for different leads.

a steel jig, it is unlikely that the pieces would be appreciably strained during this operation. That there was some residual internal stress along the cut edges is evidenced by the slight grain growth which took place with some of the purer leads if they were annealed subsequent to cutting out.

Two stresses were imposed, 500 lb./sq. in. and 350 lb./sq. in. respectively, and the temperature was 20° C.

Results

The results have been given in Tables IV to VII. Since not all features of the different leads can be shown in this way, typical creep curves are given in Fig. 1. Curves A and B are characteristic of the leads marked 1–6 and curves C and D are for the leads marked 7 and 8 respectively.

TABLE IV
DATA RELATING TO TESTS AT 500 LB./SQ. IN. STRESS STRIP "AS ROLLED"

Mark	First recryst.		Grain size mm.		Time to fracture (days)	Total elon. %	Type of fracture*
	Time (days)	% strain	Initial	Final			
1..	8	4·5	0·5	5–10	48	29·5	k.e.*
2..	14	2·0	0·3	2–10	231	25	k.e.
3..	12	2·0	0·3	2–5	214	26	k.e.
4..	22	3·0	0·3	10–15	377	27·5	k.e.
5..	3	1·0	0·3	5–20	416	26	k.e.
6..	9	1·5	0·25	up to 15	260	25	k.e.
7..	none observed		0·2	no change	774	30	i.c.
8..	„	„	0·2	no change	386	58	i.c.

* k.e. = knife edge. i.c. = intercrystalline.

TABLE V
DATA RELATING TO TESTS AT 500 LB./SQ. IN. STRESS STRIP ANNEALED 100° C. FOR 15 MIN.

Mark	First recryst.		Grain size mm.		Time to fracture (days)	Total elon. %	Type of fracture
	Time (days)	% strain	Initial	Final			
1..	12	5·5	0·5	—	34	31	k.e.
2..	70	4·0	0·25	3–5	267	25	k.e.
3..	60	4·0	0·3	Up to 5	201	30	k.e.
4..	70	5·5	0·3	2–3	357	33	k.e.
5..	40	4·5	0·3	3	184	22·5	k.e.
6..	50	4·0	0·25	2–3	326	24	k.e.
7..	none observed		0·2	No change	381	67	i.c.
8..	„	„	0·22	No change	911	29	i.c.

Curves A and B show that there is a distinct increase in the rate of creep during the recrystallisation period. This phenomenon of recrystallisation under stress was

TABLE VI
DATA RELATING TO TESTS AT 350 LB./SQ. IN. STRESS STRIP AS ROLLED

Mark	First recryst.		Grain size mm.		% Elongation			
	Time (days)	% strain	Initial	After four years	1 yr.	2 yrs.	3 yrs.	4 yrs.
1..	40	1·6	0·5	5–10	6·1	10·0	12·2	14·4
2..	320	4·7	0·25	20	6·0	9·4	10·4	11·5
3..	210	3·0	0·30	2–10	4·9	6·8	7·0	9·2
4..	210	4·2	0·28	up to 15	7·6	11·3	13·1	14·6
5..	120	3·0	0·27	5–20	5·8	7·8	9·0	10·1
6..	150	3·0	0·25	10–20	6·0	7·9	8·9	9·9
7..	none observed		0·24	No change	1·4	2.8	3·9	5·2
8..	„	„	0·20	No change	4·8	12·2	33	56*

* Broke after 3½ years.

TABLE VII
DATA RELATING TO TESTS AT 350 LB./SQ. IN. STRESS STRIP ANNEALED 100° C. FOR 15 MINS.

Mark	First recryst.		Grain size mm.		% Elongation			
	Time (days)	% strain	Initial	After four years	1 yr.	2 yrs.	3 yrs.	4 yrs.
1..	50	1·8	0·5	5–10	4·7	8·3	10·8	13·2
2..	none observed		0·25	up to 12	3·5	6·8	10·0	13·4
3..	620	5·4	0·3	5	3·3	6·8	9·1	10·9
4..	none observed		0·3	—	4·9	10·6	17·2	23·9
5..	620	7·0	0·25	5	4·2	9·0	12·3	14·5
6..	430	5·8	0·25	5–10	5·0	10·9	13·1	14·0
7..	none observed		0·22	No change	1·6	3·2	4·5	6·0
8..	„	„	0·20	No change	1·8	3·5	5·6	7·4

noted with all the leads except numbers 7 and 8. The curves for the latter two as given in Fig. 1 reveal an important difference in behaviour. For the first year and a half under stress the two curves run almost parallel and the values of total increase in length are almost identical. From this stage on, however, the two curves diverge—the creep rate of No. 8 continuously increasing and that of No. 7 continuously decreasing. These features are characteristic of the influence of silver and copper respectively.

Criteria for Judging the Creep Resistance of Lead

There is an urge, in investigating the creep properties of any group of alloys, to reduce the time required to evaluate the relative creep resistances. Results show that this cannot be done with any reliability because some features may only develop after a prolonged duration of stress. The curves C and D in Fig. 1 illustrate this point.

It is worth while then to consider the problem of deciding what criteria are available in assessing the value of any lead alloy for a particular purpose.

(1) *Time to cause complete rupture.*—This, of course, depends on the stress applied, and for the sake of comparing materials is almost valueless because at useful stresses the time for rupture is so long as to make the test impracticable. If the stresses are sufficiently high to break the specimens in a short time, then the plastic component of creep predominates whilst in use it is probably the viscous component which controls failure. Furthermore, corrosive influences are dependent on time, and this is probably important with respect to the breakdown of intercrystalline cohesion frequently associated with long stress duration.

(2) *The recrystallisation phenomenon.*—Since pure lead at ordinary temperatures will anneal and recrystallise spontaneously if deformed sufficiently, it is essential to know whether this phenomenon is likely to occur under conditions of use. In this respect it must be remembered that for many purposes lead is used at temperatures higher than atmospheric, e.g., in chemical plant, and also that in positions exposed to sunlight in hot countries the temperature may rise to 150° F. (56° C.) and that recrystallisation takes place more readily the higher the temperature. During recrystallisation the creep rate increases considerably, so that in a short time, more damage may be done than in a long time before or after the change. In the cases considered here in which recrystallisation occurred (1–6), about 5% elongation was necessary before the crystals became sufficiently distorted to bring about the change. It has been shown, however, that "as rolled" lead may retain cold work effects. In such cases, recrystallisation under stress would be expected at an earlier stage in the deformation. This is confirmed by comparing the values obtained "as rolled" and "annealed" as shown in Table VIII.

TABLE VIII
COMPARISON OF DEFORMATION TO CAUSE RECRYSTALLISATION UNDER STRESS IN "AS ROLLED" AND "ANNEALED" STATES

Condition	% deformation to cause recrystallisation Average for six leads	
	350 lb./sq. in.	500 lb./sq. in.
As rolled	3·3	2·3
Annealed	5·0	4·6

The resistance to recrystallisation can be increased by the introduction of solute atoms into the lead lattice. How small additions are effective in this direction is illustrated by curves C and D of Fig. 1 relating to solute concentrations of the order of 0·01%.

(3) *Initial creep rate.*—In order to eliminate the influence of recrystallisation, yet at the same time permit the possibility of strain hardening effects being estimated, it is suggested that the time required to extend 2% might be a suitable comparison criterion. Naturally, this time will be dependent on the stress imposed and for an industrial check it is important to use a stress as high as possible consistent with obtaining data which is not misleading. In Table IX is collected the data for the eight leads for the two stresses used, the test pieces being in the annealed condition.

TABLE IX.
COMPARISON OF INITIAL CREEP RATES OF INDUSTRIAL LEADS

Mark	Time (days) for 2% increase in length		Composition	
	350 lb./sq. in.	500 lb./sq. in.	Total impurities %	Remarks
1	60	1½	0·0023	
2	207	30	0·0087	0·002% Bi, 0·004% Sb.
3	215	18	0·0034	
4	148	20	0·0061	
5	165	13	0·0141	0·007% Bi, 0·003% Sb
6	127	14	0·0535	0·049% Bi, 0·003% Sb
7	435	83	0·0355	0·014% Cu, 0·01% Sb, 0·004% Ag
8	405	33	0·0179	0·01% Bi, 0·003% Ao

From this it will be seen that the leads fall in three groups. No. 1 creeps at a higher rate than any of the others, Nos. 2 to 6 fall into an intermediate group and No. 7 has the lowest creep rate. This holds for both stresses. Lead No. 8 is anomalous, however, in that at 500 lb./sq. in. it falls in the intermediate group and at 350 lb./sq. in. it is in the low group with No. 7. From the subsequent behaviour of these leads under 350 lb./sq. in. stress it is seen (Table VII) that after four years this anomalous behaviour is confirmed and lead No. 8 falls in the low creep rate category. It is, however, particularly susceptible to residual cold work effects, for in the "as rolled" condition (Table VI) it extended far more than any other of the leads, and had in fact broken after three and a half years. This behaviour is illustrated by the broken curve E in Fig. 1, and serves to illustrate the complexity of the phenomenon concerned. Only long time tests will reveal a feature of this kind.

From this it would seem that, with the exception of lead No. 8 the creep characteristics of the several leads are revealed by a relatively short time test of about 100 days duration at 500 lb./sq. in. A glance at Tables VI and VII will show, however, that this is a crude generalisation.

Rate of creep, however, is not the only criterion to be considered. Reference to the influence of magnesium on lead[5] shows that an alloy may reach a condition of zero creep but be quite unsuitable because of intercrystalline corrosion and embrittlement.

Conclusions

(1) The total impurity content of industrial lead is no guide to its behaviour under prolonged stress.

(2) The nature of the impurity and its specific influence must be known. Even then the influence of one impurity may be affected by the presence of others.

(3) It is suggested that for the purposes of a first classification of industrial lead alloys a test of 100 days' duration under a stress of 500 lb./sq. in. may be used, the time to extend 2% being the criterion.

(4) To supplement the latter, the test piece at the end of 100 days should be examined for embrittlement by bending and by micro examination. The latter will reveal any incipient intercrystalline weakening.

Export of Resistance Welding Machines

AT a recent meeting of the manufacturers of resistance welding machines, it was stated that in spite of the difficulties they are experiencing in obtaining raw materials, experts of spot, seam, projection and flash resistance welding machines during the first few months of 1947 were greater than the figure for the corresponding period of 1946, and further that the volume of outstanding orders for both home and overseas had been reduced slightly.

Particular interest is being shown by overseas buyers in British resistance welding machines, and manufacturers have established a firm overseas market which they are now developing. The interest of overseas buyers was noticeable at the British Industries Fair in Birmingham, where a number of resistance welding machine makers were exhibiting. Most of the machines were shown in operation, and buyers were able to see the developments which have taken place in machine design as a result of the extensive wartime experience.

The improved designs of products which are manufactured by resistance welding were also most noticeable. For example, in the holloware and kitchen-equipment sections of the Fair, the modern streamline appearance, and the light weight and strength of many of the products shown were obtained by designing the product to take full advantage of the economies resulting from welding.

Fuel Economy and Efficiency

THE Parliamentary and Scientific Committee has recently given its powerful support to the call for the more efficient use of coal. In a report submitted to the Minister of Fuel and Power and the Lord President of the Council, the Committee draws attention to the substantial benefits that would accrue from a comparatively small increase in fuel efficiency. The report states it is said that if the 1947 production of coal in this country falls to 190,000,000 tons we shall be faced with disaster, whilst 220,000,000 would give us ample for our immediate needs (apart from exports). Such estimates, however, all assume that nothing can be done about the more efficient *utilisation* of coal.

In 1913 only 15% of the potential energy in coal was turned to useful account. Even to-day, nearly 70% of our output is still to all intents and purposes wasted and not much more than 30% is turned to useful account. Thus, whereas on our present utilisation efficiency we can just "pull through" with an output of 200,000,000 tons, if we could increase this 30% efficiency by say, one-tenth, namely from 30% to 33% we would have an output equivalent to 220,000,000, which would be ample for our immediate needs (excluding exports). It is, therefore, essential that just as much effort should be concentrated on the utilisation side of the coal problem as on the production side and we are convinced that there is still much to be done in this particular field.

It should be remembered that, in former years, British industry was built up on cheap fuel conditions when no economic advantage could be gained by the expense involved on plants necessary to save fuel. In those earlier days market requirements for the products of industry generally, and of the iron and steel industry in particular, varied so much that mass production of standard materials could only be adopted to a limited extent; in consequence, it was not easy to reproduce results of fuel efficiency per ton of product such as were obtained at some foreign works operating on mass production lines. Because of these and other factors, the dear fuel period which followed the 1914–18 war found this country at a distinct disadvantage. Apart from high fuel costs at that time British industry was working with high labour costs, heavy transport charges, and heavy taxation, and its competitive powers were reduced to such an extent that capital was not available to install the plant to increase fuel efficiency.

There is no doubt that at that time, Great Britain lagged behind her foreign competitors in the scientific utilisation of fuel. While it was realised that fuel consumption in certain iron and steel producing districts was high in comparison with practice on the Continent, no real attempt to investigate the reasons was made until 1923. Since that time, however, there had been slow but steady progress up to the end of the more recent war, with the result that the amount of fuel per ton of product was gradually reduced. Among the important developments arising from the need for high fuel efficiency was the institution of fuel control departments in many works, particularly iron and steel plants.

The position of fuel, which has developed during the last few years, has increased the difficulties of industry and necessitated much wider application of fuel control departments in works to investigate fuel consumption in various stages of production, and by control, improvement of plant and operating efficiency, and by installing suitable equipment, where required to improve fuel technique. In addition, a more scientific approach to the whole subject will undoubtedly lead to still further improvement in coal utilisation. Obviously a more effective use of coal by improved technique would increase efficiency and be equivalent to a substantial increase in the coal available for other purposes, possibly for export for which there is a great need.

Referring to the experience of the coal crisis earlier this year, the report of this Committee mentions the important lesson to be drawn from the extraordinary disparity between the amount of fuel saved during the crisis of 1946–47 and the amount of consequential damage to British industry. The total saving of coal during the whole of the crisis was not more than 2 million tons. Yet it is estimated that the country lost some £200,000,000 of exports as a result. The Chancellor of the Exchequer has warned us that partly on this account the country will have to undergo severe import cuts. It seems evident that even a small gap between production and consumption of fuel at a critical period of the winter has been partially responsible for causing that further lowering of our standard of living which lies ahead. Every possible effort should, therefore, be made to insure against such a gap occurring in the winter of 1947–48.

While there has undoubtedly been a growing appreciation by the public of the importance of coal, we believe that the danger to our standard of living contained in any failure to solve the fuel and power problem is still only partially realised.

The report states that the principles which should govern the Industrial allocation of coal in time of shortage are :—

(1) That each industry should receive an allocation of coal in accordance with a system of priorities worked out in the national interest.

(2) That fuel efficiency should be encouraged and that some reward should be obtained by those firms which practise fuel efficiency better than others.

These two principles may conflict and if they do the first should be given preference. But the great weakness of the system of coal allocations during 1946–47 was that there was no adequate incentive provided for fuel efficiency. Flat rate cuts, in particular, penalise those who have been efficient more than those who have been inefficient.

The Committee believe that the new Cripps' plan for the allocation of coal is correct in so far as it provides an incentive for each firm to save as much coal as possible during the summer months.

The Committee has submitted this interim report in order to make certain proposals on the immediate problem of ensuring the minimum dislocation of industry and inconvenience to the public during the next 18 months, but it is proposed that a full report will be issued later making long-term recommendations for the better application of science to the problem of the efficient utilisation of coal.

Sinteralumina—Part I

By Felix Singer,* Dr.Ing., Dr.Phil., M.I.Chem.E., and Hans Thurnauer,† M.Sc.

Metallic oxides, because they comprise one component and one phase, permit more accurate investigation. For specific purposes these oxides are better than certain orthodox products. In this report the author describes investigations carried out on sintered alumina and explains theoretically the main factors which affect the usefulness of this material, giving particular attention to the chemistry of reaction in the solid phase and to the orientation, growth and general characteristics of the crystallites in sintered alumina in particular. In the second part of the report, attention is directed more especially to the production of sintered alumina components, their physical properties and uses. It is stated that the field of application is developing, especially for metallurgical purposes.

IN "Ceramics Yesterday, To-day and To-morrow"[1] is given the definition of ceramics as products manufactured from all inorganic materials which are first shaped by manual or other methods and then hardened by fire. This definition includes the oldest articles shaped in clay by primitive man and the most modern products on the market to-day, some of which are made from raw materials which do not even possess any natural plasticity. There are two ways in which plasticity can be conferred on these raw materials. On the one hand, they can be ground to a very fine powder, or mixed with a "binding" material, e.g., clay or organic compounds. Where the bonding is done by organic material porous ware is obtained first because the volatile compounds will be driven off on firing and only then can the mass be vitrified by sintering. On the other hand, in 1910, Count Schwerin[2] invented a process in which no additional bond was necessary. The raw material was brought into the colloid state, i.e., it was in the form of minute charged particles dispersed in an oppositely charged medium. In this state, the material could be shaped, and then fired. This invention widened the scope of ceramics enormously—almost any inorganic material could thus be used. The metallic oxides were among the most successful, and today some are even better for specific purposes than certain orthodox ceramic products. Apart from the practical advantage, the use of metallic oxides for ceramic articles provides a tool for investigating the changes which occur in the raw materials of ceramics during their manufacture to the finished product. Generally, all older ceramic masses are systems of several components and more than one phase, so that it is impossible to follow a given change during, say, firing. Any one process will be obscured by simultaneous happenings and an investigation of a single reaction will be doomed to failure at the outset. When pure metallic oxides are used, one component and one phase only are present and a more exact investigation is possible. From a study of one-component-systems the scientific background of ceramics can be elucidated for the first time.

Reactions in the Solid Phase

The science of the chemistry of reactions in the solid phase grew up very slowly, and compared with the chemistry of reactions in gases and liquids it is of very recent origin. In gases and liquids, the molecules are free to move, and as all reactions depend on the collision of molecules, they proceed much faster in fluids, where the inter-molecular forces are very low, than in solids, where the particles are held together by strong forces in a definite pattern. The three-dimensional lattice offers much greater resistance to attack, much more energy is required to move a particle from its place in the lattice than in the structureless fluids, and therefore chemical reactions are, in general, rarer and slower in the solid state of matter. This difficulty led to a slow development of the whole field. Also, before the mechanism of a reaction, i.e., of a dynamic change, can be investigated with any hope of success, a fairly complete picture of the static substance is required. The chemistry of reactions in solids thus had to wait for the great advance in crystallography due to the introduction of X-rays. Then, with an adequate knowledge of the structure of crystals and the nature of the forces holding the particles in their specific crystalline lattice, the stage was set for the study of chemical reactions in solids.

I. A. Hedvall[3] presents the general theory underlying reactions in mixtures of powders. He refers to early experiments with pure oxides, important as ceramic pigments, in which it was noticed that not only a change in the crystalline form, but also the material from which they were prepared and the type of preparation used, affected the reactivity of these oxides. The effects of the initial material and preparation are peculiar to the solid state. They were known in technically important reactions before these experiments were carried out but the reasons were obscure. The idea of different modifications was brought in to explain them, and a large number of *ad hoc* modifications found their way into the literature.

The effect of this individuality of structure on reactivity was studied in the red ferric oxide pigment. It was proved by X-rays that all ferric oxides from the most widely differing sources and methods of preparation possessed the same rhombic crystalline lattice, but that among these only one showed the bright red colour. This was obtained from the sulphate and had not been heated above 700° to 800° C. Microscopically, it was found that the rhombic lattice in the red ferric oxide was distorted and thus possessed an excess of energy in the same crystalline lattice.

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1 Felix Singer, "Ceramics: Yesterday, To-day and To-morrow." Address to the "Association of Czechoslovak Scientists and Technicians" at the Czechoslovak Institute, London, S.W.1. February 23rd, 1944.

2 Dr. Graf Botho Schwerin, German Patent Specifications No. 274039 and 276244 (January 15th, 1910 and January 16th, 1910) "Verfahren zur Herstellung hoch beständiger Gegenstände aus von natur unplastischen stoffen."

3 I. A. Hedvall, "Reaktionsfordernde faktoren bei festen stoffen." *Berichte der Deutschen Keramischen Gesellschaft*, vol. 24, 1943, pp. 318–335.

From this finding evolved the theory that faults in the lattice lower resistance to attacks, i.e., less work is required to displace particles from their assigned spot in the lattice. "Faults" are areas of higher energy. For simple crystals this theory has been developed further mathematically.

Orientation, Growth and General Character of the Crystallites

Every natural crystal deviates in some way from the ideal one pictured by crystallographers. On their lack of perfection depends the easier diffusion of particles on the surface and within the interior of the crystal so that reactions can take place. This is of general importance in all technical processes dealing with reactions among powders. A special case concerns crystalline catalysts which show that the active regions of the surface are limited to the many or few extra lattice atoms or ions-so-called active centres. Loose places or centres of disturbance at crystal defects, crystal edges and grain boundaries are put forward as such.[4]

Pure aluminium oxide Al_2O_3 can be sintered to a completely dense crystalline body known as sinter alumina. E. Ryschkewitsch started his work on sinter-alumina in 1934.[5]

He reviewed briefly the position of the refractory oxides in the ceramic industry. Ten years previously, O. Ruff[6] had succeeded in producing ceramic articles from pure oxides, and in the thirties the manufacture of sparking plugs, fine capillaries and pyrometer tubes from pure oxides, e.g., Al_2O_3, BeO and ZrO_2 presented no serious technical problem. These products had technically valuable properties and fulfilled their purpose better than other ceramic wares. In this, of course, lay a potential threat to the older ceramic industry, but this was compensated by the vast possibilities of the new field which it offered for studying ceramics on a clear-cut scientific basis. Ryschkewitsch mentioned the following problems which would be solved by investigating pure oxide systems.

Following Ryschkewitsch, recrystallisation is the reaction of a solid material with itself. It is almost impossible to follow in a system of several components, while in a one-component system one change is not obscured by various others, so it can be investigated. He states that recrystallisation in alumina is shown by the growth of crystals to approximately ten times their original size by heating at 1,900° C. for two to three hours.

The growth of the crystals can be explained by a principle of crystal growth by intermediate vaporisation first formulated by Wilhelm Ostwald.[8] The smaller crystals are not in equilibrium with the larger ones, as the former possess greater surface energy. This surface energy shows itself in different ways, one of which is a higher vapour pressure, which causes the smaller crystals to volatilise and deposit on the larger ones, increasing their size still further. As the crystals are not in equilibrium it can be said that sinter alumina is not strictly a one-phase system. It is of great interest to show that thereby sinter alumina conforms to a general principle of ceramics laid down by J. W. Mellor[9] which stated that ceramic bodies are products of arrested reactions with more than one phase and components never in equilibrium.

The influence of foreign substances on the recrystallisation of ZrO_2 (zirconium oxide) was studied. In a system of several components such a study would have been impossible.

Then, the question of softening under load at high temperatures presents itself. On this property depends the use of refractories as building materials. It is difficult to explain this process in ordinary ceramic articles. In one-component systems it has been possible to clarify this softening under load at high temperatures, e.g., in carbon. Here, the process of "gliding" occurs. The movement of the single crystals occurs at planes which show less cohesion with others. If it were possible to block these "gliding" planes then a greater resistance to weakening under pressure could be obtained. The idea of "gliding" among crystals has its origin in metallurgy. Duralumin, for example, has its greatest strength a certain time after casting. This is explained as due to the crystallising out of certain parts of the alloy from the originally homogeneous mixture, which now block the "gliding" planes. Considering the strength of refractories from this point of view (which actually has been partly abandoned in metallurgy) it ought to be possible to increase the temperature of softening under a certain load by the addition of certain "blocking materials." This has, in fact, been done for certain types of magnesite where addition of zirconium oxide increased refractoriness under load by 250° C.

In metals, orientation of crystals within a material is often possible by such directed processes as stretching or hammering or rolling. The orientated structure possesses technically more valuable properties than the random one. In oxides, this holds true also. It is specially obvious in rods and tubes of alumina, when cast tubes crack during "welding," while extruded tubes can be welded in the oxygen-acetylene flame without breaking. In this system, it is possible to follow the orientation of the crystallites, and this was done five years later.

In 1939, Ryschkewitsch's[7] paper "Recrystallisation of alumina" appeared. As defined before, recrystallisation is the only process possible in a one-phase, one-component system. It plays a great part in all solid bodies exposed to high temperatures, so it is important to study. In metals, recrystallisation is fairly well understood, while it has not been so adequately investigated in other systems.

The initial material used in Ryschkewitsch's study was very pure aluminium oxide. The hexagonal and corundum modification was employed. It was easy to separate from the unstable cubic -αform by a colour test with carmine. The material had to be ground to reduce the diameter of the particles from 25–30 μ to 1–5 μ. The necessity for this grinding can be explained by Hedvall's[3] idea of active surfaces on faulty crystals. The surface is vastly increased by grinding, and more "faults" are exposed. Any subsequent reaction is made easier and can proceed faster. During forming, the flat crystallites orient themselves, particularly if the mass undergoes some directed movement. For instance, the crystallites arrange themselves parallel to the wall of a plaster mould in a cast product. If a thick-walled article is cast, this orientation is only

4 A. King and H. Fromberz, *German English Chemical Terminology*, p. 221. (Thomas Murby and Co., London, 1934.)

5 E. Ryschkewitsch, "Einstoffsysteme als grundlage der wissenschaftlichen keramischen forschung." *Berichte d. Deutsch. Keram. Ges.*, vol. 16, p. 111. 1935.

6 O. Ruff, *Berichte d. Deutsch. Keram. Gesellsch.*, 1924.

7 E. Ryschkewitsch, "Über die Rekristallisation der tonerde." *Berichte der Deutschen Keramischen Gesellschaft*, vol. 20, 1939, pp. 477–484.

8 Wilhelm Ostwald, *Z. Phys. Chem.*, 34, 495, 1900.

9 J. W. Mellor, "Some Chemical and Physical Changes in the Firing of Pottery." *Jour. Soc. Chem. Ind.*, XXVI, No. 8, 375–77, April, 1907.

obvious on the surface which has been in contact with the mould. In the middle of the wall there is no orientation. If an article is extruded, the crystallites lie in the direction of the applied force. This is an example of artificial fibre structure comparable to the structure of a metal-wire.

Th. Ernst and H. v. Wartenberg[10] put forward another theory concerning the orientation of crystallites in alumina if they are not lamellar in structure. They consider that differential absorption of water at the base and at the side planes causes orientation. The bases will tend to adhere to the walls of the container and to the moist basal planes of other crystallites, thus producing some orientation. "Selected growth" in the "C" axis during firing will increase this orientation.

"Selected growth" is part of the process of recrystallisation. When crystals grow into each other the direction of growth of the larger is generally adopted. The mosaics of similarly oriented crystals may finally result in huge single crystals, often a thousand times greater than the initial material. As growth is quicker vertically than horizontally, real columns may result. But this phenomenon is rare in recrystallisation and it is also undesirable. Normally, sinteralumina, consists of crystallites equally formed in all directions, of fairly uniform size, even if the initial material showed variations in size. Crystal growth occurs at a definite temperature, about 1,800° C. This is in accordance with a rule set up in metallurgy for the fritting of metallic powders. The temperature of sintering is about 0·8 to 0·9 of the temperature, of melting. For most purposes, small crystallites in the lattice are better than large ones. As large crystals are produced in presence of mineralisers, all impurities must be removed from the mass before firing.

Crystallites in sinteralumina are not completely homogeneous. They contain gas bubbles, which are definitely within the crystals and not at the junctures between separate crystallites. As the gas bubbles are completely enclosed, there is no effect on the apparent porosity of the material.

The Properties of Sinteralumina

From this description of orientation, growth and general character of the crystallites in sinteralumina, the properties of this material can be derived.

For instance, the breakage of an extruded tube can be explained. A break along the long axis is due to the orientation of the crystallites along this axis and lines of weakness between them. Occasional slits across the tube can be explained by recrystallisation of the crystallites during firing in the direction across the tube so that the weak lines run across, between the long columnar crystals.

Also in a bowl of sinteralumina cracks may form in concentric circles round the break. This is due to the peeling off of orientated crystallites, which were bedded parallel to the wall of the mould.

Another type of breakage can be explained by orientation. In a thick-walled article a crack may only form to a certain depth in the wall. If the body was in contact with "mineralisors" (catalysts) on the wall of the mould their action will only have extended to the surface layers of the cast. The large crystals, which possess a weaker impact strength, will break more readily than the small crystals in the interior. In the opinion of Ryschkewitsch, the localisation of inclusions in the interior of the crystallites and not at grain boundaries, as already mentioned above, is of greatest significance for the gas-tightness of the body made of sinteralumina. Apart from that, the localisation is of significance in such cases in which the utmost possible smoothness is required as, for instance, in thread guides for artificial silk. It is better to smooth the crystals in the "fire skin" by means of softly acting polishes, than to remove the closed crystal layer by previous grinding with hard substances, such as Sic or B_4C, whereby the fine inclusions, i.e., microscopic cavities, are laid free. The fact whether the surface in question can or cannot be polished depends on the formation of the inclusions, which in turn is closely bound to the crystallites. Occasionally, on one and the same body differently polishable surfaces can be observed.

Gas-bubbles present an impassable obstacle to recrystallising sinteralumina. Thus it is almost impossible to weld together two tubes, unless the surfaces to be welded are quite plane, without heating them nearly to the melting point of alumina. This property enables sinteralumina to form very exact capillaries, which are not deformed by jutting crystals out into the interior of the capillary.

After this general investigation one property of sinteralumina was singled out and studied over a wide temperature range; compressive strength was studied in 1941.[13]

Mechanically, the most resistant ceramic products are porcelain and steatite, their resistance to pressure in the cold is 7,000 kg./cm.^{2} Based on theoretical considerations it could not be expected to possess a great resistance to load at high temperatures, while the sintered metallic oxides should keep this property even at high temperatures.

In Ryschkewitsch's experiment, cubes of 6 mm. length were fixed between alumina layers, lubricated with pure natural graphite and crushed in an hydraulic press. The pressure was given by a manometer and the temperature read on a thermocouple. The experiment lasted only a few seconds.

The behaviour of the cubes is of interest up to 1,000° C.; they explode on reaching the limiting pressure for the given temperature. Even the crystallites themselves are partly crushed. Above 1,000° C. there is plastic shattering. At about 1,400° C. the cube breaks along a diagonal plane, so that there are two pyramids; it looks as if the weakness there lay in a gliding plane.

A theoretical value has been derived for the impact strength of an ideal crystal. The figure is given as 10^5 kg./cm.^{2} This is not reached by any technical material.

The data for sinteralumina are given, and are shown in the graph Fig 1. In the cold, an almost theoretical figure of 3×10^4 kg./cm.^{2} is reached, but even at 1,000° C. the compressive strength is technically interesting. In the neighbourhood of the absolute zero, obtained by extrapolating the curve, the compressive strength rises to 4×10^4 kg./cm.^{2}

Later, the tensile strength[13] was investigated and

10 Th. Ernst and H. von Wartenberg, "Die Kornregelung in sinterkorund." *Zeitschr. Fur angewandte mineral.*, 1, 115, 1937.

11 E. Ryschkewitsch, "Uber die druckfestigkeit einiger keramischer werkstoffe auf der einstoff basis." *Berichte d. Deutschen Keram. Gesellsch.*, 22, 1941, pp. 54–55.

12 A. Smekal, *Ergebnisse der exakten naturwissen schaften*, 15, pp. 106–188, 1939.

13 E. Ryschkewitsch, "Uber die zerreissfestickeit Einiger keramischer werkstoffe auf der einstoff-basis." *Berichte d. Deutschen keram. Ges.*, 22, (1941), pp. 363–371.

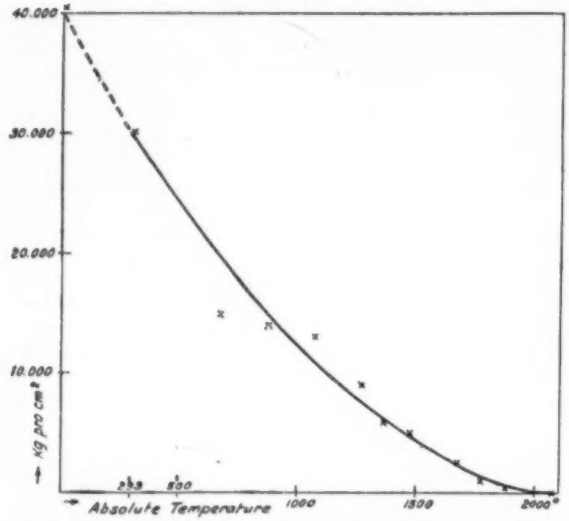


Fig. 1.—Compression strength-temperature curve of sinteralumina.

plotted as a function of temperature. In ceramic products on the silicate basis there was no reason to suspect this property to be high at high temperatures, so it had not been investigated. Porcelain, for example, has a tensile strength of 300 kg./cm.² at room temperature which is minute compared with that of steel, i.e., 8,000 to 10,000 kg./cm.² It was, however, expected that ceramic products on the single oxide basis should show high tensile strength at high temperatures, particularly after the results with compressive strength were known.

Rods of circular cross section were used as test bodies. They tapered slightly towards a narrowing in the middle where the rod broke when the limiting force was applied. A small electric heater surrounded the test-rods for work at high temperatures. As before, the experiments lasted only a few seconds. Sinteralumina

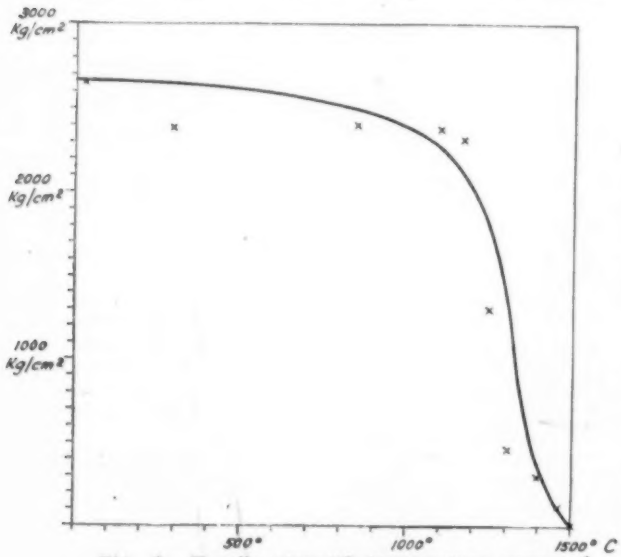


Fig. 2.—Tensile strength-temperature curve of sinteralumina.

and other oxides were tested. It was found that the tensile strength increased with decreasing diameter of the rods although experimental difficulties were encountered when very thin rods were used. The values obtained, and their variation with temperature are shown in the graph Fig. 2.

Characteristically, it was found that the tensile strength of single oxide ceramics exceeds that of the earlier ceramic products and only begins to drop steeply after 800° C. to 1,000° C.

The appearance of the surface of the fracture is of interest. The break actually involved single crystals, so that the forces between the crystals (intercrystalline) must approach the forces within single crystals (intracrystalline). This shows a contrast to metals, where the intercrystalline forces are lower than the intracrystalline forces, i.e., a break would occur between single crystals, but would never go through them.

Young's modulus of elasticity (E) was then investigated,[14] E is characterised by the equation

$$E = \frac{l}{\delta l} \cdot \frac{P}{q}$$

where l – length of the body under test
δl = extension of this length
P = force applied
q = area of cross section
when $l = \delta l$ and $q = 1$
E = P

So that E is the force required to stretch a rod elastically by its own length—provided the cross section of the rod is unity. E really represents the molecular resistance of a material to deformation.

As ceramic bodies belong to the brittle materials, they will extend by a small fraction of their length only before breaking. This creates a difficulty for accurate experimenting. Ryschkewitsch overcame the difficulty by clamping the test rod at one end and weighting the free end. The height through which the rod was bent by the force applied was measured, and E worked out from the equation :—

$$H = \frac{l}{E} \cdot \frac{4}{3\pi} \cdot \frac{l^3}{r^4}$$

Where H = height
l = length
r = radius

At high temperatures, the body was tested in a specially constructed electric furnace. It can be seen from the equation that any errors in the measurement of the diameter will be magnified enormously. Greatest accuracy was thus required in measuring the diameter. In fact, the diameter in the direction of the bend and the diameter at right angles to it were measured and the mean of the two values weighted to approach more closely the value of the more important diameter in the direction of the bend.

Again, the experiments were performed in a few seconds. This was done to conform with previous experiments and to prevent the effects of a permanent set which almost any body suffers under prolonged exposure to bending stresses.

E of sinteralumina was first measured by H. Gerdien[15] who obtained a value of $2 \cdot 35 \times 10^6$ kg./cm.² This is not higher than the figure for good steel. Since this measurement the manufacture of oxide materials has

14 E. Ryschkewitsch, "Elastizitätsmodul einiger oxydkeramischer werkstoffe auf der einstoff basis." *Berichte der Deutsch. Keram. Gesellsch.*, 23 (1942), pp. 245–260.

been improved and a higher value could be expected. It was found to be $5{\cdot}88 \times 10^6$ kg./cm.^{2} The value for pure crystals of corundum is $5{\cdot}2 \times 10^6$ kg./cm.^{2}, so that E is of the same order in the polycrystalline sintered body and in the single crystal. The variations of E with temperature were measured and are given in the graph Fig. 3.

The smoothness of the curves proves that there are no other processes occurring in the sinteralumina than the steady fall in the forces of cohesion with rising temperature.

Above, it has been shown that tensile strength rises with a decrease in the diameter of the test rod, and E was tested for a similar correlation. The same tendency was shown.

The deductions of this curve, which can be extrapolated to both sides are of great theoretical interest. At infinitely small diameter E rises to the maximal value, existing in a single corundum crystal. At large diameter the value falls to the lowest determined figure: $2{\cdot}8 \times 10^6$ kg./cm.^{2} It is, at present, only possible to construct almost perfect polycrystalline bodies of small diameters, and as the best values for E are obtained at small diameters, the forces between the crystallites of perfectly formed polycrystalline bodies must almost equal the intracrystalline forces.

From the curve, Fig. 4 the quantitative proof of the closeness of these forces can be read off. Before, the same statement could only be made qualitatively from examination of the surface of the break in the rods tested for tensile strength. The modulus of elasticity is probably truly slightly lower in sintered bodies than in single crystals, because the former are probably less perfect than a single, well-formed crystal.

E is reduced by impurities, as could be expected.

From a knowledge of E and the tensile strength a precise figure can be given to the brittleness of sinteralumina.

All these properties described above were investigated in fully sintered products. It was now necessary to study the development of these properties during firing. As the most representative property E was chosen.[16]

From the literature it was found that the volume of some oxidic-systems decreases at first slowly with temperature. After a definite temperature, specific for the material in question, is reached the volume decreases very rapidly.[17]

Also the mechanical strength of products fired at different temperatures rises slowly at first, and rapidly later.[18]

In these experiments the decrease in volume, and the modulus of elasticity were measured on products fired at different temperatures. A priori, little more than a general similarity of the curves could be expected. The results showed, however, that the curves were concurrent over their whole course and that there were two points of inflexion, which divided the curves into three distinct parts. (Fig. 5).

The first part shows a gradual rise in E and a decrease in volume with temperature. In the next part the curves bend upward very suddenly. E rises steeply and the volume falls steeply with temperature. In the

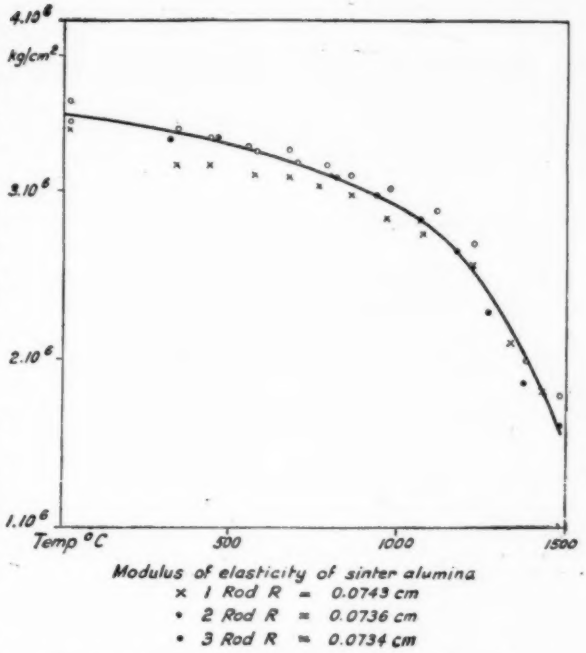


Fig. 3.—Graph showing the fall of E with rising temperature.

third part, both curves run parallel to the base, showing that both properties are independent of temperature after a certain degree has been reached, which is about 1,750° C. for sinteralumina.

The firing thus occurs in two steps, the first below 1,550° C., the second between 1,550° C. and 1,800° C. Closer insight into these steps was gained from a study of thin sections of the sintered material. Sections of alumina fired at 1,410° C. could be crushed under the coverslip and broken into crystallites of about the same size as the initial material. Even at 1,600° C. there is no significant increase in size of the crystallites, but at 1,780° C. some growth has taken place, and the product

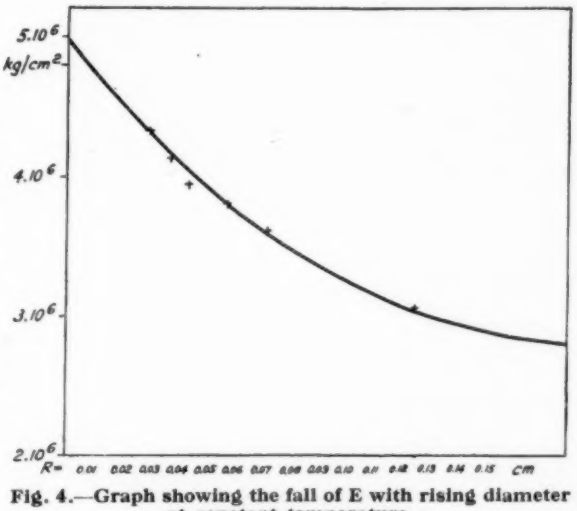


Fig. 4.—Graph showing the fall of E with rising diameter at constant temperature.

15 H. Gerdien, *Zeitschrift für Elektrochemie*, **39** (1933), p. 15.
16 E. Ryschkewitsch, "Sinterungsgrad und Festigkeit keramischer werkstoffe." *Berichte d. Deutschen Keram. Ges.*, 25 (1944), pp. 95–112.
17 R. Lucas, "Untersuchungen über die feuerschwindung." *Zeitschr. für physikalische Chemie*, **52** (1905), pp. 327–342.
18 W. Eilender and R. Schwalbe, "Festigkeitseigenschaften von sintereisen." *Arch. für Eisenhuttenwesen*, 13, pp. 267–272 (1939).

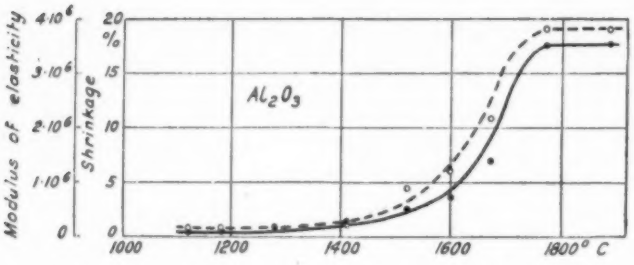


Fig. 5.—Graph showing increase in E and decrease in volume (shrinkage) with rising temperature.

is very strong. There is no longer a possibility of crushing the section under the coverslip. At 1,910° C. the crystallites have grown further, but are not otherwise different from these at 1,780° C. The alteration of the structure thus occurs in the steepest part of the curve. This is not only true for sinteralumina but for all other single oxide systems investigated.

Decrease in volume, increase in mechanical strength (as characterised by E) and crystalline structure form three facts of the same phenomenon, i.e., of the degree of sintering of the initial material. As the graphs show definite changes, sintering must depend on two processes, among the crystallites which are governed by two sets of forces. The first part of the curve depends on surface forces only. The surface of the crystals adhere. This idea had been put forward in 1916 by E. Podszus, but he referred the whole process of sintering to surface forces.[19] These forces are relatively weak, and they rise only slowly with temperature. This superficial joining of individual crystals has been defined as fritting. After a definite temperature has been reached the crystals lose their identity and grow into each other. The forces concerned here are the same as those within the single crystal. When this growth process has finished there is no change on further heating. The ideal sintered material should show the same forces as the single crystal. In practice, they are always slightly lower, as explained above.

A further paper on plastic deformation of brittle bodies followed.[20] Corundum, in the form of sapphire was found to be plastic by investigating scratches made on it with sintered ruby under the microscope. The plastic deformation rises with temperature.

(*To be continued*).

Forthcoming Meetings

THE Institute of Metals will hold the 39th Annual Autumn Meeting in Glasgow from September 23rd to 26th inclusive. An interesting programme has been prepared for members and their ladies. In addition to the business and technical meetings, visits to works and factories have been arranged, various receptions and a dinner and dance. There seems every indication that this post-war meeting in the Scottish centre will long be remembered. The papers to be presented for discussion at the technical sessions include: "Surface Effects During the Annealing of 70–30 Brass"; "The Centrifugal Casting of Copper Alloy Wheels in Sand Moulds"; "Frictional Properties of Some Lubricated Bearing Metals"; a joint discussion on some published papers on "The Corrosion of Magnesium Alloys"; and "Metallographic of the Precipitation of Copper from a Silver-rich Copper-Silver Alloy."

The Sheet and Strip Metal Users' Technical Association is holding its Annual General Meeting and Autumn Conference at the Waldorf Hotel, London, W.C. 2, on September 25th and 26th, at which papers will be presented for discussion on: "Sheet Metal Brazing"; "The Application of Paint to Metal Surfaces"; and "Deep Drawing with Special Reference to Lubrication."

On October 15 and 16 The Institute of Metal, in association with other societies and institutes, present a Symposium on Internal Stresses in Metals and Alloys at the Institution of Mechanical Engineers, Storey's Gate, Westminster, S.W.1.

On September 17-20 the Third International Conference on Electrodeposition will be held at the Hyde Park Hotel, Kensington, S.W.1. The Council of the Electrodepositors Technical Society has arranged an excellent programme and a good attendance of foreign visitors is expected.

Staff Changes and Appointments

Mr. JOHN BOLTON has resigned his position as assistant secretary of the Institute of British Foundrymen to take up an appointment in London with the Institute of Cost and Works Accountants, which he will take over at the beginning of October.

Mr. H. HALLIDAY, O.B.E., relinquished his appointment as Director of Refractories in the Ministry of Supply on August 31st. All communications and inquiries regarding refractory products should now be addressed to the Ministry of Supply, Metals Division (M.2), Shell Mex House, London, W.C. 2.

Dr. HUGH O'NEILL, M.Met., F.I.M., chief metallurgist of the L.M.S. Railway Company, has been appointed to the Chair of Metallurgy at University College, Swansea, and began his new duties on the first of this month. Educated at the University of Sheffield and for thirteen years lecturer in metallurgy at the University of Manchester, Dr. O'Neill joined the L.M.S. Research Department in 1934 and shortly afterwards became chief metallurgist. He is the author of the well-known book on "Hardness of Metals," which is regarded as a standard work in its field, and has contributed many papers to Engineering and Metallurgical Institutions on a wide range of subjects.

THE Council of Industrial Design have appointed Mr. GORDON RUSSELL, C.B.E., M.C., R.D.I., Director of the Council. He has had a long experience in the field of industrial design.

Mr. T. A. Sullivan has retired from the London organization of Wm. Canning & Co., Ltd., after 24-years service and has taken up a new appointment as commercial manager to the International Corrodeless, Ltd., Lockfield Avenue, Brimsdown, Enfield, where he will continue to maintain his contacts with those in the electroplating and finishing industries.

Recent Welding Research Reports

The first issue of "Welding Research," the new official organ of the British Welding Research Association, contained two reports, one dealing with the strength of spot welds in mild steel sheet, and the other with welded stanchion joints. In a succeeding issue, two further reports were presented dealing with welded constructions under fatigue-loading conditions and heat-treatment of welded constructions, respectively, and in this article a resume is given of these reports.

THIS report describes an extensive investigation made under various conditions of time, pressure, and current. The work was initiated at the request of the Resistance Welding Machine Manufacturers, and its objects were :—

(1) To provide data for the standardisation of resistance welding machines.

(2) To obtain exhaustive fundamental data on machine settings and weld strength and quality as a basis for the preparation of a Code of Practice on the Spot Welding of Mild Steel.

The question of the consistency of weld strength was given particular attention, since it is this factor, more than any other, which governs the economical application of the welding process. It was clearly established from the tests that by the use of optimum settings and careful control of the welding variables, the consistency of weld strength could be readily controlled to within very fine limits.

Recommendations.—In the absence of any standards for the dimensions of spot welds, it has been possible to put forward recommendations based upon the results obtained from the use of optimum machine settings established as a result of the tests. These recommendations include reference to spot weld diameter, weld nugget penetration, surface indentation, and sheet separation—all important factors from the point of view of the design of components for resistance welding.

Values of the welding variables recommended for the production of the standard spot welds are absolute, and for this reason they are applicable to any type of machine which can reproduce them. Subsequent tests on four different types of machines have shown that weld strength can be pre-determined to within 5% by setting the variables with the use of instruments prior to welding, irrespective of the type of machine in operation.

Slight fluctuations in the values of the variables during welding cannot be entirely avoided under production conditions, by reason of fluctuations in line voltage and air pressure. Inasmuch as the results of the investigations on the effect of the welding variables are functional, it has been possible to determine the change in weld strength produced by 5% changes in any of the variables, from which the relative importance for control over each of the variables can at once be seen. The recommended values of the optimum settings have been chosen particularly with a view to the minimisation of fluctuation of weld strength as a result of fluctuation of the welding variables.

Welded Stanchion Joints

This report—a statement on welded stanchion bases, caps and joints—summarises the information brought out in the deliberations of the Committee on Codes of Practice for Welded Structures, which has for more than two years been engaged on the preparation of the clauses for a code of practice on the use of welding in building structures. This statement will be followed by two further statements :—

(1) Welded built-up girders and compression members and

(2) Beam-to-column and beam-to-beam connections, and by the complete recommendations which the three statements are meant to introduce and explain.

The work was undertaken with two principal objects in view. First, the provision, at the request of the Institution of Structural Engineers, of clauses for inclusion in the welded steel construction section of the code prepared by that Institution for the Codes of Practice Committee for Civil Engineering, Public Works and Building, and secondly, the preparation for the British Standards Institution of recommendations on which a revision of B.S.538 "Metal Arc Welding in Mild Steel as applied to General Building Construction" could be based. This task is now substantially completed and the results will shortly be made available to these Institutions for their respective uses.

The preparation of such recommendations is but one aspect of the work of the B.W.R.A. in the field of structural engineering, and is concerned primarily with the use of welding in conjunction with present methods of design and construction, based essentially on the treatment of frames as "pin-jointed." Future developments in the application of welding are likely to be associated mainly with rigid frameworks, in the construction of which welding shows to particular advantage and a second and more significant aspect of the Association's work is concerned with the strength and design of rigid members, joints and complete structures.

In this latter respect, a major experimental investigation was commenced about nine years ago under the direction of Professor J. F. Baker, and it has proceeded since then without interruption, being housed during recent years at the Engineering Laboratory, Cambridge. Expressed simply, the object of the work is to determine experimentally the real load-carrying capacity of a rigid frame work up to the point of collapse, and then to develop a design method, based on the data so obtained, which will take full account of the elastic and plastic strength of the steel and which may be readily and rationally applied in the practical design of rigid frames.

Effective Carrying Capacity.—Present design methods have been evolved with special reference to structures which are, conveniently but inaccurately, assumed to be "pin-pointed," and are based on values for working stresses, load factors, effective column lengths, and so on, which have no meaning when applied to rigid frames. It is manifestly unsound to attempt to design a monolithic structure in accordance with rules laid down in

specifications such as B.S.449 and the L.C.C. Bye-Laws and it has been demonstrated clearly in the experimental work already completed that the effective safe carrying capacity of a stanchion in a frame may under certain conditions be three or four times greater than that allowed for example by B.S.449.

Testing has so far, been carried out on model frames, covering various conditions of single and double stanchion curvature, loading arrangement and so on, and the results have been reported in four interim progress reports which have appeared from time to time in the Transactions of the Institute of Welding. Arrangements are now in hand to extend the experimental work to full scale frames, which will be erected at the B.W.R.A. research station at Abington Hall, near Cambridge.

Concurrently, analytical and theoretical work has been in progress and a start made on the development of what may be termed the "plastic design method." Attention has first been concentrated on the simple rectangular portal frame, and a team of designers, representative of leading constructional engineering firms, has worked with the research team at Cambridge on the production of typical designs, based on the plastic method and, for comparison the requirements of B.S.449. The results have shown in respect of the former method appreciable savings in weight of steel in frames designed for similar load conditions and load factor.

Fatigue Loading Conditions

A report concerned with "Recommendations for the Heat Treatment of Welded Constructions in Mild Steel" describes preliminary development work and investigations on the behaviour of welded constructions under fatigue loading conditions, a subject to which it is intended to devote increasing attention as the testing facilities at the B.W.R.A. research station at Abington are expanded. A considerable amount of research has been carried out in various countries to determine fatigue strength of welded joints and details, but very little has been done in studying the behaviour of complete structures, or units of construction, in which such joints and details are embodied.

Amongst the few examples which may be cited in this latter respect are the investigations conducted in America and Germany, on somewhat parallel lines, to determine the relative merits under repeated bending loading of different types of butt welded and cover plate joints in rolled steel beams, and of different methods of welded flange reinforcing plates to such beams. Where, in such tests, the pulsating load is applied directly to the specimens, the testing installation requires to be of a very substantial size and capacity, and the equipment is naturally very expensive.

Faced with the impracticability of purchasing such equipment, the B.W.R.A. concentrated its efforts on the construction of apparatus for the fatigue testing of constructions by the resonance vibration method. By this method, which is described in detail in the report, it is possible to subject structures to rapidly alternating loading conditions, using comparatively inexpensive equipment. Four welded H-beams have been tested and the apparatus which was built has been shown to work extremely satisfactorily. In addition, exploratory tests have been carried out to demonstrate the suitability of the resonance vibration testing technique in application to various types of construction including spot welded light alloy beams, and butt welded railway rails.

Four testing units have now been installed at Abington Hall, and a programme of experimental work has been put in hand. The programme includes a long-term fundamental investigation on the effects of residual stresses on fatigue endurance, and a short range series of tests to provide information on the comparative merits under fatigue bending conditions of different constructional details in stiffened plate members which are representative of ship construction.

Heat Treatment

The heat treatment of welded constructions is considered in a report on "Fatigue Tests by the Resonance Vibration Method on Four Welded H-beams." The recommendations contained therein are put forward as being representative of existing good practice, and were compiled on the basis of present knowledge and experience. It is recognised that much remains to be said on this subject, and it is hoped that a programme of experimental work will be initiated, dealing in particular with the problems of local heat treatment.

Copper Production

THE British Commonwealth, according to the current issue of the Bulletin of the Copper Development Association, now leads the world in the production of copper, the annual output being approximately 700,000 short tons, compared with 604,000 short tons, the next largest output, produced by the U.S.A.

"The consumption of copper continues to increase," the Bulletin states. "For 1946 it averaged 27,100 tons a month in this country, compared with 24,100 tons in 1945 and 21,500 tons in 1938. The American demand is extremely heavy and cannot be satisfied by domestic production, with the inevitable result that competition for supplies outside the United States is severe.

"Figures, given below, indicate the dominating position of the British Empire, second only to that of Latin America, in potentiality as an exporting community.

Copper in thousands of short tons

	Reserves	Annual Production	Annual Requirements
United States	20,000	604	1,268
Latin America	28,100	600	10
British Empire	25,500	700	392
Europe (excluding Russia)	2,200	150	759
Russia	10,000	390	172
Africa (excluding British Empire)	7,360	160	(Small)
Far East (excluding British Empire)	500	50	210
TOTAL	93,660	2,664	2,811

"The final column gives the annual requirements of new metal, excluding scrap, and indicates that the world demand for copper is somewhat higher than current world production, leading to depletion of stocks.

"It is clear that the United States and Europe are the chief buyers of copper, while Latin America and the British Empire are the only communities with any considerable production in excess of their annual requirements. The most important information to be derived from the data, however, is that at the present rate of production the reserves cited will be exhausted in 35 years. Lower grade ores, at present uneconomical to work, may have to be used, and much activity in prospecting for new deposits is in progress, especially in America. Unexplored reserves in Rhodesia are reported to be very extensive, and may be supplemented by deposits in South West Africa."

"Infra-Red" Heating by Gas—Its Development and Practice To-day*

By J. B. Carne, B.Sc.

Appliances to effect heat transfer now cover a range of temperatures from 10° F. for refrigeration to about 3,400° F. for metal treatment. But the process of evolution in design continues and new appliances appear either embodying improvements on existing practice or using a new technique. Infra-red appliances have been developed to meet a distinctive industrial heating technique. This technique and some fundamental qualities of infra-red are discussed. Particular attention is directed to infra-red equipment in practice.

The Range of Application of "Infra-red"

The stoving and curing of paints on metal accounts for the majority of "infra-red" applications, but its use for other purposes is growing rapidly. In metal finishing it is also used with considerable advantage for the "burning-in" process of bitumen coatings in the preparation of metal for acid etching and electro deposition, for the drying of rinse water from metal articles between successive processes in plating, for stoving following phosphate protection treatment, and for the evaporation of water from frit coatings in the vitreous enamelling of sheet and cast iron. The time saving of "infra-red" over convection methods is emphasised in the processes associated with multi-coat finishes applied in the finishing of machine tools. In one typical example which necessitated the application of primer, filler and stopper, under- and final enamel coats, the total times for processing the coats by "infra-red," convection, and natura drying were 26 minutes, 4 hours, and 11 hours, respectively.

"Infra-red" is also being successfully employed in various stages of pottery and other ceramic manufacture, for the curing of rubber and in the production of plastic materials, whilst its efficiency for the evaporation of water from slurries, pulp and for the heat-treatment of impregnated textiles has been proved in the laboratory.

Gas "Infra-red" Equipment in Practice

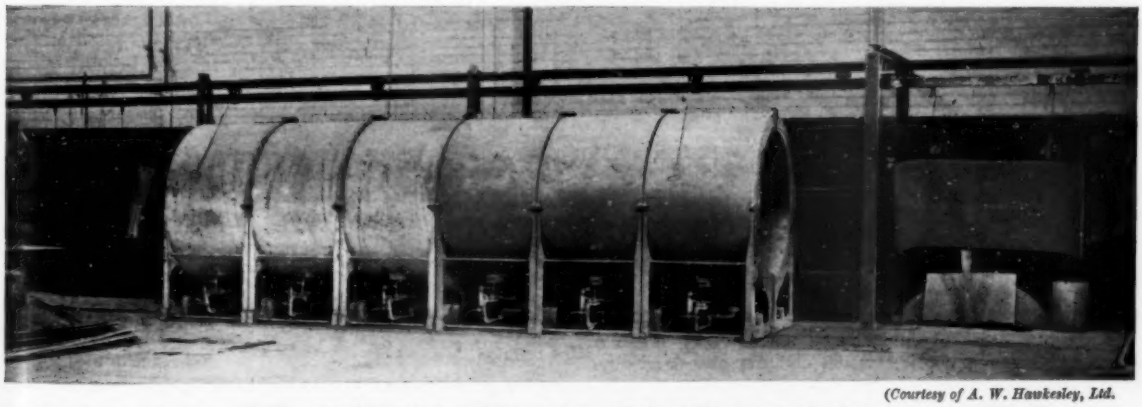
It will be appreciated that while the general principles of heat transfer outlined must apply in all the processes involving "infra-red," and in consequence an appropriate technique must be common to all applications, the wide variety in the nature of the materials and in the shape and dimensions of the articles treated, as well as the quantities and methods of production, call for a correspondingly wide variety of "infra-red" ovens.

In selecting installations representative of the scope of "infra-red" practice and the equipment specifically designed for "infra-red" processing, preference has been given to those which are used for the treatment of metal articles and which have features of design and operation illustrative of "infra-red" technique.

The tunnel unit.—The cylindrical tunnel shown in Fig. 5 is the well-known "G.L.C." type, originally designed to meet the urgent demands in wartime production. Its construction and performance were fully described by Andrew and Chamberlain before a meeting of the Institute of Fuel in 1943.[5] It is simple in principle and construction, consisting essentially of two semi-cylinders, the interior linings of which are maintained at any desired temperature up to 650° F., by a row of gas jets fixed along the base of each semi-cylindrical section. Hot gases of combustion pass through the tapered space between the curved lining and a refractory insulating layer, and leave through a slot which runs the full length of each section. The whole of the lining, by virtue of its temperature, emits relatively long wave "infra-red" radiation and its performance does not involve the use of any reflecting surfaces. Ovens of similar design, with modifications such as oval instead of circular cross-sections, multiple instead of single burners, corrugated instead of plain radiant linings, have also been constructed and proved suitable for particular manufacturing

* Continued from page 196 August issue.

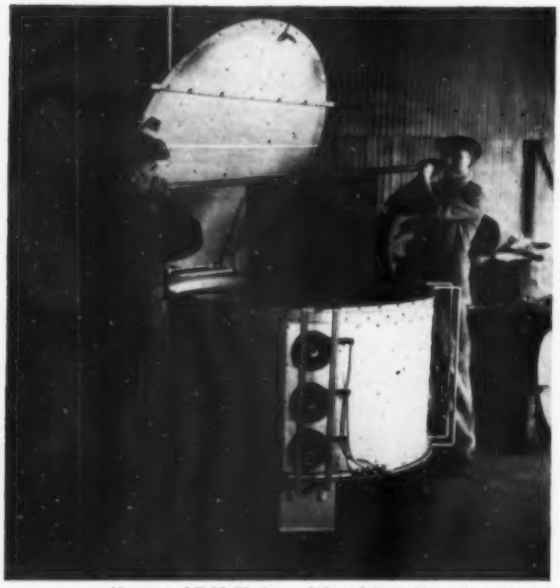
5 L. W. Andrews and E. A. C. Chamberlain (1943), *Proc. Inst. Fuel.*



(Courtesy of A. W. Hawksley, Ltd.

Fig. 5.—A circular section "infra-red" tunnel of the G.L.C. pattern, consisting of six tunnel sections, each 3 ft. long and 3 ft. diameter.

Fig. 6.—A high-pressure gas radiant heat burner.



(Courtesy of Keith Blackman, Ltd., and South Metropolitan Gas Co.).

Fig. 7.—A cylindrical box oven, constructed for the rapid stoving of searchlight cases, in which the heating is effected by " infra-red " radiation and high-temperature air provided by 12 high-pressure gas radiant heat burners.

requirements. Details of the development and application of a number of such ovens formed the subject of a paper[6] by Atkin.

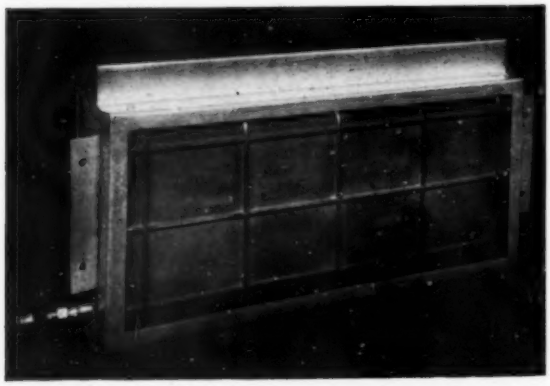
The installation shown in Fig. 5, is employed for the stoving of paint on the components of aluminium prefabricated houses, and a throughput of 2,000 components per day is achieved. As would be anticipated from geometrical similarity a circular section oven is particularly suitable for articles of circular or squarish section, but such ovens have also proved satisfactory for the treatment of narrow section articles. Three standard diameter ovens are in normal use, 2 ft. 6 in., 3 ft. and 14 ft.

6 F. L. Atkin—*Gas Times* (1944), Sept.

The H.P. gas radiant heat burner.—As its name implies this unit operates on high pressure gas, the highly aerated flames of which by impinging on the surface of a 3 in. diameter circular disc of heat-resisting steel sheet, raise the disc to approximately 1,100° F., and so provide a source of radiation comparatively rich in near visible " infra-red " (Fig. 6). The units can be arranged in any assembly to provide an appropriate intensity of radiation ; a single unit and a box-type oven incorporating 12 units are seen in Fig. 7. In the illustration the painted sheet metal case of a searchlight is seen being lifted from the 4 ft. diameter cylindrical oven after an exposure of 15 minutes to the " infra-red " radiation and the high-temperature air from the incandescent discs. The unit is suitable for providing " infra-red " in tunnel ovens, an application which indicates the flexibility of a system based on the unit-heater principle.

The unit panel system.—The varied requirements for " infra-red " in the finishing and treatment of metals have been met successfully by the application of the unit panel seen in Fig. 8.

This unit which operates on town gas at normal mains pressure, is designed for providing fields of radiation of almost any contour and of any intensity required in the " infra-red " range of processing. Each unit, when operating at 30/10 in. w.g. pressure, emits approximately 4,000 B.Th.Us/Hr. in the form of " infra-red " radiation and 1,500 B.Th.Us/Hr. in air heated by the radiant panel. Lower outputs are readily obtained by suitable adjustment of the control tap in the gas supply to a heater or a group of heaters and thus the two conditions,



(Courtesy of De La Rue Gas Development, Ltd., and South Met. Gas Co.)

Fig. 8.—The gas " infra-red " unit panel heater, has overall dimensions of 22 in. × 10 in. × 4 in. and can be used at any inclination within 45° to the vertical. It has a gas rate of approximately 0.1 therm./hr. at 30/10 in. w.g. pressure and provides " infra-red " radiation and high-temperature convection.

i.e., a controlled field of radiation and an elevated air temperature in the " infra-red " zone, previously stated as being essential to satisfactory and economical processing, can be provided by suitable assembly of the units.

Ovens comprising from 2–80 units and employing various arrangements, many of which are depicted in the diagram Fig. 9, are in use for processes in metal finishing and treatment.

The tunnel shown in Fig. 10 is used for the stoving of synthetic enamel on steel furniture having overall sectional dimensions of 72 in. × 20 in. To induce

uniform temperature in a tall article heated mainly by radiation, it is necessary to irradiate the lower parts of the article more intensely than the upper, in order to make good the greater rate of convective loss which naturally occurs from them. This required gradation of intensity is readily obtained in unit panel ovens by operating the lower rows of units at pressures greater than those used for the upper rows. Ovens employing these units have a comparatively low heat capacity since apart from the units themselves the oven consists of only the skeleton steel structure and the metal sheet walls, and in consequence full operational output is attained in about 20 minutes.

The batch-operated oven seen in Fig. 11 is of special interest in so far that in order to raise the temperature of the relatively massive junction heads of the wheel forks of the cycle frames at the same rate as that of the sheet metal disc wheels, and so attain uniformity in paint stoving, the top rows of unit panels are operated at a gas pressure higher than that of the lower rows.

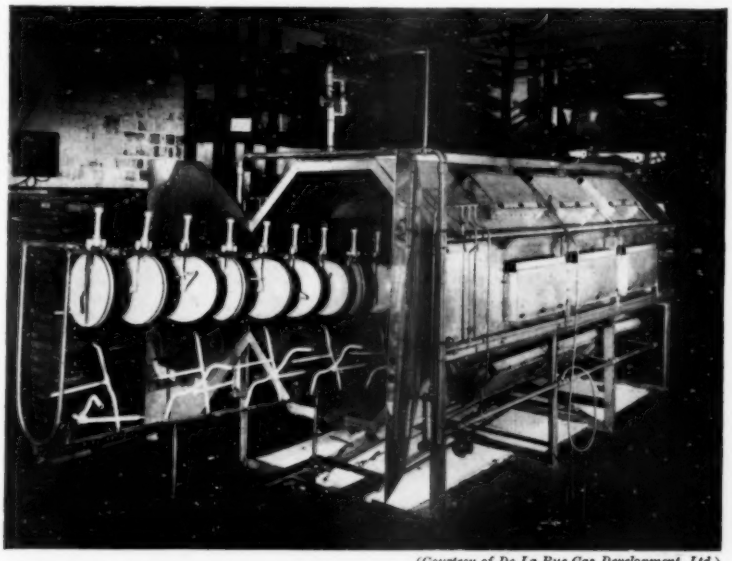
The horizontal belt conveyor oven seen in Fig. 12 is designed for the drying of frit coatings on sheet steel prior to the fusing process of vitreous enamelling.

Wet frit coating on 20-gauge steel sheet are dried in 4 minutes and the oven has a capacity for drying about 600 sq. ft. of coated sheet per hour.

The conveyorised tunnel shown in Fig. 13 is used for the drying of rinse water on metal castings, each weighing 2 lb., prior to a plating treatment. This oven is designed to treat articles, long and narrow in section, and row above row of flattish section smaller articles.

(By Courtesy of Richard Thomas & Baldwins and Stewart Gill & Co.).

Fig. 10.—A 50-unit panel tunnel, with integral conveyor, used for the stoving of paint on articles of large overall cross section. The interior dimensions of the tunnel are 15 ft. × 7 ft. × 3 ft. 6 in.



(Courtesy of De La Rue Gas Development, Ltd.)

Fig. 11.—A batch-type oven, incorporating 18-unit panels. For the stoving of cycle frame forks, the top row of heaters are operated at a higher gas pressure than the lower. Satisfactory stoving is accomplished in 6 minutes.

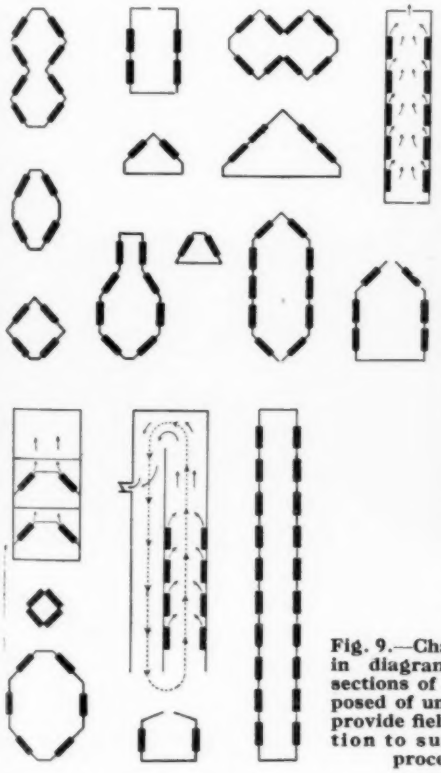
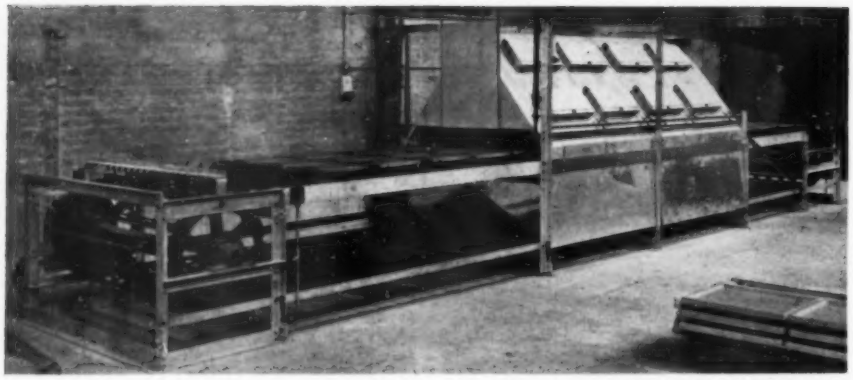


Fig. 9.—Chart showing in diagramatic form sections of ovens composed of unit panels to provide fields of radiation to suit various processes.

High intensity "infra-red."—An elementary point often overlooked when considering radiant heat processing, is that a high radiant temperature is necessary not only for raising materials to high temperature, but also in ovens of compact design for heating large throughputs of material to comparatively moderate temperatures. For instance, although curing of a certain synthetic resing enamel requires attainment of a temperature of only 400° F., in order to construct a compact oven for the stoving of the enamel on 3 tons of 24 gauge steel sheet, per hour, an equivalent radiant temperature of about 900° F. must be provided. Similarly an equivalent radiant temperature of 750° F. is required for the rapid stoving of a low temperature (260° F.) bake paint on steel

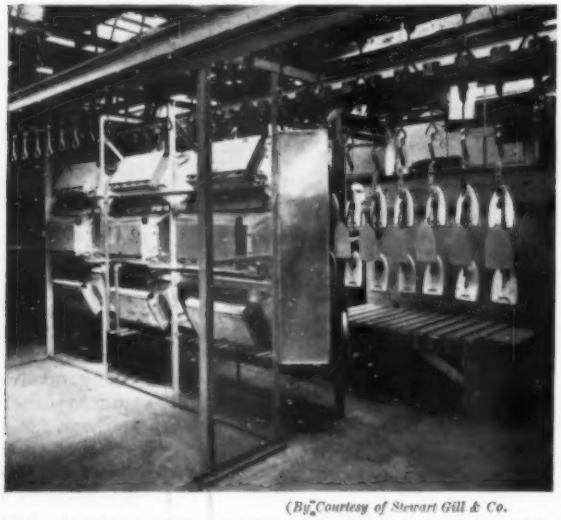


(By Courtesy National Enamels).

Fig. 12.—A 16-unit panel oven, with slatted conveyor belt, for the drying of water wet frit coatings on steel, prior to the fusing of vitreous enamel. Ovens of similar section are used for stoving of paint on metal articles, plastic radio cabinets and in food preparation. The largest in actual use is 75 ft. long × 4 ft. wide.

cylinders 8 in. diameter, 9 ft. long and weighing 300 lb. each, a treatment which has been accomplished, using the unit panels, in a mater of 12 minutes.

The rapid soldering, using tinman's or silver solder, of masses of small articles is frequently required and here again relatively high intensity "infra-red" conditions are necessary. The oven seen in the photograph Fig. 14 is of a design used for the fusion of 340° F. M.P. solder and fluxpaste on toy steam boilers en masse. The oven accommodates 50 components and an exposure time of 3 minutes is necessary, thus allowing a throughput of 800 soldered components per hour. The components may be put through the oven on trays as illustrated or directly on to a mesh conveyor belt. With closer packing of the units than used in the oven shown, an equivalent radiant temperature of 1,300° F. is attained, at which high M.P. silver solder on a brass box, of 16 g. wall thickness, is fused in 3 minutes. An air temperature of more than 1,000° F. is also established in an oven of this design, which, with the high radiant temperature, enables aluminium and magnesium-aluminium alloy sheets up to 16 s.w.g. thicknesss to be raised to more than 400° C. in 2 minutes, for reducing the hardness acquired during drawing operations.



(By Courtesy of Stewart Gill & Co.

Fig. 13.—A narrow section "infra-red" tunnel, incorporating 18-unit panels, for drying rinse water from heavy metal plates.

In an oven similar to that seen in Fig. 14, 24 g. stee sheet is raised to 420° F. in 35 secs. during which exposure a coating of a synthetic enamel is cured satisfactorily. Lead oxide paste on accumulator plates is also dried satisfactorily in a similar oven during an exposure of 90 seconds, thus enabling a throughput of 1,200 plates per hour leaving the pasting machine in single file, to be achieved in a 32-unit panel oven, 17 ft. long.

The rapid stoving of anti-corrosive primer paint applied by dipping on large sheets of steel and large angle iron frames, called for a correspondingly large narrow and vertical heating zone through which the articles could be conveyed. In Fig. 15 the parallel walls of heaters, each containing 40 units and approximately 20 ft. high × 15 ft. wide, are seen with a paint coated 18 g. steel sheet passing between. It will be observed that from each unit a vent into the heating zone is provided, so that the hot flue gases from the units are used to raise the ambient air temperature. Again in this

(Courtesy of South Metropolitan Gas Co.)

Fig. 14.—A diamond section oven, in which an equivalent radiant temperature of 900° F., with upward and downward radiation is used for mass soldering of metal components. Tunnel ovens of similar section are used for "burning-in" process of bituminous coatings on metal and evaporation of water from wood laths.

installation uniform temperature of the large sheet is induced by operating the lower rows of units at a higher gas pressure than the upper rows, and thus the greater convection losses on the lower portions of the articles are countered by more intense radiation.

When smaller sheets and frames are stoved only the appropriate rows of units are put into operation, so that the gas rate is matched to the heat requirements of the throughput and the utilisation efficiency of the system is maintained.

The extent of the fields of "infra-red" radiation which can be provided by the assembly of these units, is virtually unlimited. To date the largest horizontal heating zone is one 75 ft. long × 4 ft. wide, which effects an equivalent raidant temperature of 600° F. and an air temperature of 260° F.

The installations described cover the commercially available gas systems which employ equipment specifically designed to cater for the "infra-red" range of industrial processing, but limited space prevents mention of the great variety of industrial gas-fired radiant heat equipment specially constructed to meet the needs of particular processes. For heat-treatment at conditions beyond the "infra-red" range, as defined earlier in this article, what might be termed furnace conditions are called for and the effectiveness of gas-fired radiant heat apparatus for this field is proved and already well-known.

(Courtesy of Luxfer, Ltd.)

Fig. 15.—An extensive "infra-red" heating zone provided by two opposing walls 20 ft. high × 15 ft. wide, each containing 40 unit panels. The control of radiant intensity essential to uniform heating is readily attained by control of gas pressure.

Fatigue of Ferrous Materials

Some Factors that Influence Resistance to the Damaging Effect of Fatigue Stressing

Several aspects of fatigue, in its relation to ferrous materials, were discussed at a recent meeting of the American Society for Testing Materials. Some of the papers are considered, including the damaging effect of fatigue, means of improving the fatigue resistance of low-alloy steel axle shafts, fatigue tests on steel under compressive stress, and the fatigue testing of ball and roller bearings.

THE damaging effect of fatigue stressing above the endurance limit was discussed by J. A. Bennett[1] who experimented with notched specimens of a steel containing 0·28–0·33% carbon, 0·4–0·6 manganese, 0·20–0·35% silicon, 0·8–1·1% chromium, 0·15–0·25% molybdenum (X4130). Tests were also made with smooth specimens in an effort to determine the cumulative damage caused by fatigue at more than one stress. Test specimens were prepared from normalised steel, a different heat being used for each part of the investigation. The notched specimens had a cylindrical test section 0·35 in. diameter, into which was cut a semicircular circumferential notch 0·05 in. deep and 0·05 in. radius. Stresses were calculated for the minimum section of 0·25 in. diameter without regard to stress concentration. The smooth sections had a minimum section 0·25 in. diameter with a contour radius of $9\frac{7}{8}$ in.

All the fatigue tests were made on R. R. Moore type machines. Auxiliary apparatus used, included a deflection measuring micrometer, a stroboscopic viewing device and a travelling microscope for counting and measuring fatigue cracks. With such apparatus it was possible to evolve a deflection method for detecting the formation of a fatigue crack which permitted the damage measurement to be limited chiefly to the precrack stage.

Tests were conducted in the conventional manner (to fracture) on a group of notched specimens to determine the S-N and the fatigue limit. Four stresses in the range between the fatigue limit and the yield strength of the steel were used, 42,000, 48,000, 54,000 and 60,000 lb./sq. in. With unnotched specimens complete S-N curves were determined for specimens after each of eight different damaging treatments consisting of various cycle ratios at stresses of ± 48,000 and ± 54,000 lb./sq. in., Table I. Exploratory tests were also made to verify previous investigations on the repair of fatigue damage.

The results obtained from the various tests showed that, if damage occurring at one stress was determined by measurements at another, the apparent rate of damage depended on the value of both stresses. When the first was larger than the second, the damage occurred

1 Amer. Soc. Testing Materials, 1946, Preprint No. 33, pp. 1–19.

TABLE I.—PRE-STRESS CONDITIONS (BENNETT)

Stress, lb./sq. in.	Cycle Rates
± 48,000	10 33⅓ 66⅔ 90
± 54,000	10 33⅓ 66⅔ 90

rapidly at first then more slowly, and the reverse was true when the first stress was the smaller. The S-N curves for specimens after various damaging treatments showed that with increasing damage, the absolute value of the slope of the falling part of the curves increased and the fatigue limit decreased and these differences in the S-N curves provided a measure of damage with the help of which damage occurring at different stresses could be directly added. Fatigue damage prior to the start of cracking was repaired by understressing but not by heat-treatment.

Other conclusions obtained from the results were that the slope of the falling part of the S-N curves for the same material in smooth, notched and cracked specimens showed approximately the same stress concentration ratios as the fatigue limits. The number of cracks formed in a specimen before fracture increased rapidly as the test stress was raised above the fatigue limit. The length L of fatigue cracks might be represented by the equation $\log (L-C) = \alpha N$ where C and α are constants and N is the number of cycles. In specimens stressed considerably above the fatigue limit, the number of cracks M in a narrow circumferential band of the specimen could be expressed by the equation $\sqrt{M} = KS$ where K is a constant and S the average stress in the band. The development of a small crack in a specimen resulted in a large decrease in the value of the fatigue limit as compared with the specimen which had been stressed just short of cracking.

Improving Fatigue Resistance

An investigation was carried out by O. J. Horger and C. H. Lipson[2] to evaluate the fatigue resistance of production automobile axles shafts and to determine means for improving their fatigue resistance. The effect of cold-straightening, three degrees of shot-peening and recarburisation on the fatigue strength were determined. All the axle shafts were tested in rotating bending as cantilever beams in double-ended fatigue machines rotating at 1,500–2,200 r.p.m. and all the axles were tested at a constant stress for a period of at least 30 million stress reversals unless failure occurred before that time. The axles were unmachined in the tapered body portion between the splined end and bearing seat adjacent to the wheel, and fatigue failure in service and in the test carried out, was found to develop in this body section.

The 88 axles shafts used in the investigation were made from a steel containing 0·49–0·53% carbon, 0·88–1·05% manganese, 0·39–0·53% chromium, 0·52–0·62% nickel and 0·16–0·23% molybdenum (N.E. 8650). The influence of seven different conditions on these axles, all of which were subjected to a heat-treatment consisting of subcritical annealing at 715° C., heating to 800° C. for 2 hours, quenching in a high-speed oil and tempering at 440°–450° C., was investigated

2 Amer. Soc. Testing Materials, 1946, Preprint No. 29, pp. 1–22.

TABLE II.—SUMMARY OF ENDURANCE LIMIT VALUES FOR PRODUCTION AXLE SHAFTS IN ROTARY BENDING

Test Series	No. of Axles Tested	Straightened	Shot-peened		Carbon Restored	Endurance Limit Tons/sq. in.	
			Shot	Arc Height		Min.	Max.
A ..	20	Yes	Nine	None	No	5·8	7·1
B ..	10	No	„	„	„	—	8·9
C ..	12	Doubtful	No. 28	0·012 A2	„	19·2	21·4
D ..	12	„	No. 25	0·017 A2	„	19·2	21·4
E ..	12	„	No. 22	0·024 A2	„	21·0	22·3
F ..	12	Yes	None	None	Yes	6·2	8·0
G ..	10	Yes	No. 22	0·024 A2	„	22·3	—

as designated by the test series A to G summarised in Table II. The 46 axles tested in series C, D, E and G, were shot-peened under the conditions shown in the table. Most of the axles investigated were cold-straightened. The shafts in series B, however, were deliberately not straightened, as a means of investigating the influence of straightening upon fatigue resistance. The 22 axle shafts in test series F and G were also given a carbon restoration treatment, after forging and before quenching and tempering, the recarburisation treatment consisting of heating the shafts for 5 hours at 900° C. in an RX gas atmosphere of balanced carbon potential. Slow cooling in the same atmosphere prevented surface decarburisation. Series G shafts were shot-peened, but series F shafts were not peened after heat-treatment and straightening.

The results obtained showed that on the basis of the tests carried out axles not straightened had about 25% greater endurance limit value than those straightened, where axles were not shot-peened and surfaces were decarburised. This decrease in fatigue resistance was accompanied by surface tensile stresses of about 50–60 tons/sq. in., induced by cold-straightening. Shot-peening of straightened axles gave about three times the endurance limit of similar straightened axles not shot-peened. Axles which were recarburised and then accidently slightly decarburised in heat-treatment showed no real increase in fatigue resistance over similar axles not recarburised and having a much deeper decarburised layer.

Fatigue Tests Under Compressive Stress

The results obtained from fatigue tests of rail steel under compressive stress were reported by R. S. Jensen and H. F. Moore.[3] Test specimens were machined from vertical strips cut from the web of a 112 lb. rail. To ensure failure starting in a region of high compressive stress, as it had occurred in a rather large number of rails in service, the specimens were designed with a T-shaped minimum cross-section and were tested as cantilever beams in partially reversed flexure, with the maximum tensile stress on the top surface of the stem equal to 20% of the maximum compressive stress. The shape and dimensions of the specimen limited the maximum tensile strength on the bottom of the specimen to 57% of the maximum compressive stress on the top surface of the specimen. In all fatigue failures during the tests on specimens of this shape and size, the fatigue cracks started on the top surface of the T on the " compression side " of the specimen.

In some of the test specimens the ¼-in. top surface of the stem was left in the as-rolled condition, in some specimens it was left in the as-rolled condition with the imprint of a steel stamped number at the critical section.

3 Amer. Soc. Testing Materials, 1946, Preprint No. 38, pp. 1–8.

and in still other cases the specimen was shot-peened on both top and bottom surfaces. Two sets of specimens were tested with the critical section in the shape of a rectangle (sides of flange of T section milled off) under cycles of reversed flexural stress. One of these sets had polished surfaces at top and bottom and the other had one surface left in an as-rolled condition. In all cases the thickness of the specimen was very nearly the full thickness of the web of the rail. All specimens were tested in two vibratory type fatigue-testing machines at 800 r.p.m.

The specimens of steel rail tested under the range of stress described showed an endurance limit under 10 million cycles of stress 77% higher than those obtained for corresponding cycles tested under cycles of completely reversed stress, and the fractures for such specimens were found to start on the compression side of the specimen. Under a stress range from maximum compressive stress to tensile stress 20% as great, a marked reduction of fatigue strength resulted in specimens with stamped numbers at the critical section of the compressive surface of the specimen. Shot-peening was found to raise the fatigue strength 32% above the fatigue strength of as-rolled specimens for this range of partially reversed stress.

Ball-bearing Fatigue

Metallographic observations of ball-bearing fatigue phenomena were carried out by A. B. Jones[4] on a high carbon chromium steel containing 0·95–1·10% carbon, 1·2–1·5% chromium (S.A.E. 52100). This steel was used hardened to a complete martensitic structure with a Rockwell C hardness of 63–65, and, as a ball-bearing race material, was subjected to very heavy compressive stresses, sometimes exceeding 450,000 lb./sq. in., and under special circumstances as high as 750,000 lb./sq. in.

Microexamination of ball bearings of this steel run to failure under controlled laboratory conditions showed certain changes to take place in the structure of the steel. In the martensitic structure consisting of well distributed carbide, concentrated areas of troostite appeared some thousandths of an inch below the surface and such scattered areas increased in size and frequency as the running time was increased. The density of these troostite areas was found to be dependent upon the magnitude of the load and the length of time a bearing was run at a given speed. Similar results were obtained with special experimental bearings heat-treated according to standard ball-bearing practice and subject to a compressive stress on the inner race way of almost 800,000 lb./sq. in. In highly-stressed bearings, where a maximum troostite concentration was obtained, horizontal grey lines began to appear in the structure.

To explain the gradual change from martensite to troostite and the development of grey lines noticed just before the ultimate fatigue life of a bearing was attained, a study was made of the conditions of stress and strain which exist in a ball-bearing rotating under load. From such a study it was concluded that some point beneath the surface of the race way during the operating cycle of the bearing was subjected to the greatest amount of shear strain energy and hence to the greatest amount of heat and that this heat caused tempering of the hard martensite. Continuous application of load produced further heat and caused the area of tempering to spread, and, since the ultimate tensile strength of the material bears a definite relation to the hardness and the hardness in turn was reduced by continuous application of heat, the effect of continuous running was to reduce the strength and hardness of the material so that it could no longer support the stress imposed and failure occurred. The grey lines produced in long-lived bearings, when the ultimate fatigue life was approached were considered to result from plastic flow brought about by the shear stress above the reduced elastic limit of the troostic material at the point of maximum heat generation and the grey colour of the lines was due to a change in the structure of the material itself in the neighbourhood of plastic strains.

4 Amer. Soc. Testing Materials, 1946, Preprint No. 45, pp. 1–14.

Fatigue-testing Machines for Ball Bearings

An account was given by H. R. Gibbons[5] of the methods and machines used for testing roller bearings and determining their load ratings. Typical bearing testing machines were briefly described including early spring loading units applying both radial and thrust loads, and later units loaded by hydraulic cylinder having a radial capacity of 30,000 lb. and a thrust capacity of 15,000 lb., respectively. A new machine, with radial and thrust hydraulic cylinders, having load capacities of 300,000 and 150,000 lb. was also referred to. Consideration was also given to the development of speed load life curves for the rating of bearings and to the question of bearing life dispersion.

One of the principal factors influencing speed load relationship dealt with was lubrication, and two others dealt with work hardening of the roller operating surfaces in low speed ranges, and bearing precision. Factors affecting bearing life tests also discussed were the type of steel used for rollers and races and the heat-treatment of bearing parts.

Fatigue testing machines for ball and roller bearings were described by T. Barish[6] who also discussed such problems in machine design as deflections and resulting misalignments, shaft and housing wear, and lubrication. The large scatter obtained in bearing fatigue tests was discussed, and a certain amount of the scatter in life tests was considered to be due to variations in the steel used for roller bearings. Satisfactory fatigue tests were carried out using loads giving a life of more than 3,600,000 cycles. For 500 r.p.m. and one stressing per revolution such a test required 120 hours.

5 Amer. Soc. Testing Materials, 1946, Preprint No. 46, pp. 1–7.
6 Amer. Soc. Testing Materials, 1946, Preprint No. 42, pp. 1–15.

DORMAN LONG (AFRICA), LTD., a subsidiary of Dorman Long, Middlesbrough, have been appointed main contractors for the structural design and execution of the whole of the steel buildings and structures in the new South African Steelworks at Vanderbijl Park, Vereeniging, Transvaal. The contract comprises at least 45,000 tons of structural steelwork, to a value exceeding £3,000,000, and is the largest overseas contract secured by British Structural Engineers since before the war. Dorman Long will co-ordinate the whole work and sublet to other South African structural firms such portion of the work of fabrication as will ensure completion at the earliest date before the end of 1949.

The placing of this order for the whole of the steelwork in connection with the Iscor steelworks is not only a tribute to the Dorman Long organisation, but an indication of the great value of the British structural steel industry to the export trade of this country.

Stress Corrosion Cracking of Welded Mild Steel Gas Mains

THE problem of cracking in welded steel gas mains is one which is of some concern to the gas industry and investigations on the subject have been in progress for some time by the F.M.9 Committee of the British Welding Research Association. The work is not yet completed but it is felt that an authoritative statement regarding the present position of the investigations would be helpful to those concerned. With this in view the Committee responsible for the work has prepared the following short statement.

In the past few years the cracking of welded mild steel gas mains and plant used in coal-gas production has presented contractors and gas engineers with a serious problem, but it should be noted that failure has occurred only in the portion of the plant after condensation and prior to ammonia extraction. There are not many cases in all to examine and most of them have probably been recorded. Cracks have occurred solely inside gas works where welded mild steel pipes are exposed to crude coal gas and not in gas mains carrying purified coal gas inside or outside the works.

Some twelve months ago, a brief statement was made in the technical press referring to investigations on this problem which were being undertaken by a Committee of the British Welding Research Association, on which there are representatives from the Gas Research Board and the British Iron and Steel Research Association in addition to members of industrial and university research laboratories. The committee feel it wise to publish tentative conclusions at intervals in order that interested parties may be aware of the progress of the work. The following paragraphs summarise the position, as it is understood by the Committee at the present time :—

(1) The stress corrosion cracking of welded gas plant is a particular case of the general phenomenon of intercrystalline cracking. Data from other cases of inter-crystalline cracking have been valuable in examining the present problem.

(2) The fact that welded steel gas plant is subject to stress corrosion cracking indicates the combined presence of a state of stress in the steel and of a specific corrosive liquid medium.

(3) There is so far, no evidence to show that differences in welding technique have influenced the incidence of cracking.

(4) In certain other cases of inter-crystalline cracking, met with in industry (which may or may not be analogous to the cracking of welded steel gas mains), considerable benefit can be obtained by thermal stress-relieving processes or by shot-blasting. It is possible that the solution of the problem of the cracking of welded gas mains may be found in one or other of these treatments, but it will probably be important to specify fairly accurately the method of procedure, since cases are not unknown where incorrect treatments of this kind have made matters worse.

(5) Observations have suggested that the oxidation products of ammoniacal liquor constituents, such as ammonium thiocyanate are an important factor in producing corrosion of this type.

(6) Field experiments, covering various types of steels and other factors, have been instituted in gas works where failure has already been experienced. Many data have been obtained from accelerated laboratory tests which have been used as a guide in planning the field tests, but it must be appreciated that results from such tests may not be precisely parallel with those from actual gas works.

(7) It is hoped that the field experiments may, particularly in conjunction with laboratory work still proceeding, give us further information on the chemistry and the mechanism of the cracking so that the conditions for establishing immunity will be more fully understood.

Record Output of Ironfoundries

THE output of iron castings in the second quarter of this year amounted to 714,787 tons, which is equivalent to an annual rate of production of 2·86 million tons. This, according to the Council of Ironfoundry Associations, is the highest output which has ever been officially recorded. It has been achieved in spite of shortages of skilled labour and essential materials (foundry pig-iron and cupola coke). If these handicaps could be removed, to allow the existing capacity of the Ironfounding Industry to be fully employed, even higher outputs could be reached.

Blanking, Piercing and Forming

READERS are advised that the paper on the above subject, dealing with the development of zinc alloy tools for sheet metal parts, which was given at the Winter Conference of the Sheet Metal Industries, has been reprinted by kind permission of the authors, Mr. J. W. Sladden and Mr. H. S. Walker, a copy of which may be obtained on request to Imperial Smelting Corporation, Ltd., 37, Dover Street, London, W. 1.

Obituary

It is with the deepest regret we have to announce the death of Mr. Andrew Jollie on August 22nd at his home in Coldingham, Berwickshire, following an operation. Mr. Jollie retired from active participation in the affairs of The United Steel Companies, Ltd. in October, 1945, after completing nearly 50 years in the steel trade, the last 25 years of his life was spent at Messrs. Steel, Peech & Tozer of which company he was Chairman. He was also a Director of The United Steel Companies, Ltd.

Not only was Mr. Jollie a well-known figure in the steel trade of Sheffield, but he was respected and admired throughout the whole of the industry. He had been a leading figure in the wheel, tyre and axle trades and was Chairman of the National Association for Rolled and Re-rolled Steel Products, in the formation of which he was one of the principals. Another important activity was that of Chairman of the Billet Associations, and it was through his knowledge and initiative that he was able to take an active part in the reorganisation of the control of the steel industry.

Mr. Jollie lived a strenuous and active life, and during his business career saw many ups and downs in the steel industry, but he always had complete faith in the ability within the industry to weather the storms and overcome the many difficulties which presented themselves.

Co-operative Research Activities

The Work of the Research Associations is Outlined

The gulf that formerly existed between scientific knowledge and its application to the needs of mankind has gradually narrowed until to-day it is generally appreciated that industrial progress is dependent upon the ability to apply scientific knowledge effectively. The rate of progress is necessarily variable, because additions to the store of knowledge, or the use to which it is put, vary from time to time. In the ferrous and non-ferrous metals fields additions to knowledge arise from competitive research, co-operative research, and independent academic research. For some years past British Governments have fostered co-operative research and, in keeping with our policy during recent years, reports from these research organisations are given to indicate the work done, in progress or contemplated, in order that industries concerned may be able to take advantage of the facilities these Associations provide for their advancement.

THE provision of the essential requirements for an ever-increasing population presents problems that can only be solved by persistent research to establish ascendency over disease, to increase the production of food, economise motive power, reduce the limitations of the products capable of being obtained from the raw materials of the world, and in cheapening production. All the various sections of research are concerned in the general advancement involved. Although past years have given birth to many remarkable discoveries, development, on the whole, is gradual because of the need of research to perfect and widen the scope of these discoveries. Research is, therefore, necessary so that advances can be made in stages that are more readily applied. Some discoveries are in advance of progress and may be partially or wholly forgotten, others, on the other hand, are so much needed that little time separates them from application.

In much progressive work of this nature, particularly that associated with industry, economic considerations demand the exploration of every avenue likely to give better and cheaper products. It is for this reason that the larger manufacturers appreciate the need of special laboratories, adequately staffed and equipped, not only to assist in maintaining the normal standard of their products, but in developing new products and revising the technique of production. Not all manufacturers, however, can support a research laboratory for their own work, and to overcome this difficulty co-operative research provides an excellent means of serving particular fields of industrial activity. This form of research is carried out by research associations which are supported financially by their respective members and by the Government. Here special attention is directed to the research associations within this journal's field and brief reviews are given of their service.

The British Iron and Steel Research Association

Teamwork in Research in Co-operation with Suppliers and Users

On the research side of the British iron and steel industry there is a strong basic organization. Nearly all the steel works have well equipped and well staffed research laboratories and some of these are outstanding. Much supplementary work, however, is being successfully carried out on a co-operative basis and a considerable portion of this is of a "background" nature. In this review is outlined the main sections of research on which the above Association is engaged.

FOUNDED in 1945, and in effective operation only from the end of that year, the British Iron and Steel Research Association has had to achieve maturity at a precocious rate. In order to keep pace with the live demands of the industry of which it is part, B.I.S.R.A.'s organisation has been defined and established during the first two years of its existence, and may now be said to be reasonably stable.

Actually the Association was off to a flying start, as before its inception the steel industry had already organised a considerable amount of co-operative research. The British Iron and Steel Federation had organised a number of joint committees with the Iron and Steel Institute in many important fields of research, and had set up a technical department of the Federation under the Iron and Steel Industrial Research Council. All these activities, together with those of another small but active party in South Wales, provided a substantial nucleus for the Association's work on its foundation, and are all now embodied in its programme.

At the present moment B.I.S.R.A. operates five independent labcratories or experimental stations of its own; has a total staff of some 180, and is responsible for a large volume of research projects in Universities, other research associations, the N.P.L. and, above all, at the works and laboratories of its member firms. In all some 300 projects are on hand, ranging throughout the industry's production cycle from raw material and blast furnace to draw bench, rolling mill and finished products.

The Association is organised in six largely autonomous

divisions, corresponding to the six main divisions of the industry, and three, so to speak, horizontal departments (Physics, Chemistry and Engineering) which carry out more fundamental work and work common to a number of divisions. These departments perform an incidental function of considerable value in maintaining liaison between the divisions.

The work of each division is controlled by a panel, composed of 12 expert members drawn from the industry or outside it, and each panel in turn appoints committees to cover the various sections of its work. Altogether some 450 voluntary members on over 50 committees control and canalize the Association's work.

The following summary indicates the main lines of research on which the Association is engaged, supplementary and complementary to the very great volume of research carried on by the individual firms within the industry.

Iron Making Division

The work in progress on blast-furnace burdens is directed towards obtaining knowledge of the best conditions and proportions of the constituents of the burden and the best methods of obtaining these in practice. Such knowledge is directed towards the improvement of the product and economy of operation, though the blast furnace is, in fact, already an instrument of high thermal efficiency.

In connection with the actual processes at work inside the blast furnace, model work has continued on the distribution of materials. Particular attention has been paid to the influence of methods of practice and furnace construction on its distribution, such as the revolving top, the effect of unsymmetrical discharge of materials and the use of layer charging. These questions, of course, raise engineering problems, on which the Ironmaking Division of the Association works closely with the Plant Engineering Division, and a conference of technicians was organised in June, 1947, by these Divisions jointly for discussion of the layout of blast-furnace plant.

Experiments on the penetration of heat and gas into lump ore are also being carried out.

The Association's experimental blast furnace at Stoke-on-Trent with a 1 ft. 9 in. hearth (thought to be the smallest in existence actually making iron) is used, of course, in connection with these investigations.

On blast-furnace practice a series of recommended procedures has been prepared for special operations such as shutting down, isolating and blowing out. This booklet has been circulated to operating staffs.

The burning question of coke quality has also received attention, and as a result of a joint conference with the British Coke Research Association a standard specification is being discussed. Another conference has discussed the use of carbon hearths, while scaffold formation is being studied, and blown out furnaces are examined as opportunity offers.

Steel Making Division

Besides the " baby " blast furnace at Stoke-on-Trent, the Association also has there an experimental open-hearth furnace, of which a description has been published.[1] Here considerable work on furnace design has been carried out, for example in connection with the Maerz port and other open-hearth developments.[2]

There has also been much work on instrument control, and a report has been published on instrumentation, with recommendations for installation and use.[3] The industry's programme of conversion to oil fuel on a large number of open-hearth furnaces, and the unfamiliar problems raised made this report particularly timely. A conference was also held on the subject of oil firing.

Pyrometry is an allied subject, and much work has been done in this connection, particularly at the N.P.L., and a report has been published on the measurement of brightness temperatures of liquid steel streams.[4] Further work is directed towards improvement of equipment,[5] and a backwall installation recently devised by a member of the industry is being studied. The Physics Department has constructed a black body furnace for calibrating pyrometers up to 1,700° C. This furnace has a 3-in. aperture, and is thought to be the largest of this type attempted.

A great deal of work has gone into the development of a suitable brick for the all-basic open-hearth furnace, the adoption of which would effect considerable economies. The Association's Chemistry Department has been largely instrumental in this work. The position now is that as a result of the work of a joint committee of the British Refractories Research Association and B.I.S.R.A. such a brick is being manufactured in this country. It has equal and in some respects superior properties to those of the pre-war German and Austrian Radex " E " brick, and arrangements for works' trials of all-basic furnaces using this product are far advanced.

Other research projects on the subject of steel making include :—

On the chemistry side, a general investigation on the behaviour of sulphur in the open-hearth furnace, both practically and theoretically.

Ingots and ingot moulds, their design and dressing are long standing subjects of research, initiated by the Research Council of the B.I.S.F.

The determination of the gaseous content of steel in liquid and solid states and their relations to steel quality.

Much work has been done on gas producers, in conjunction with the British Coal Utilisation Research Association.[6,7]

Mechanical Working Division

Coating, rolling and drawing projects are the three main lines of interest in the work of the Mechanical Working Division.

The equipment and opening on July 3rd, 1947, of the Association's laboratories in South Wales[8] has given added facilities to the work on distribution and thickness of zinc and tin coatings, the porosity of tinplate and the geometrical characteristics of metal surfaces. Work in progress on rolling includes a fundamental study of the plastic deformation of metals at Cambridge University with special reference to the behaviour of material between the rolls. Practical studies on a two-high rolling mill at Sheffield University, of the factors involved in cold-strip rolling have been described in published form,[9,10,11] and investigation there continues into the effect of back and front tension during rolling.

1 *J.I.S.I.*, March, 1947, 405.
2 *J.I.S.I.*, March, 1947, 392.
3 *Metallurgia*, April, 1947, 278.
4 *J.I.S.I.*, Jan., 1947, 55.
5 *J.I.S.I.*, April, 1947, 568.
6 *J.I.S.I.*, May, 1947, 55.
7 *J.I.S.I.*, July, 1947, 371.
8 *Metallurgia*, July, 1947, 161.
9 *J.I.S.I.*, Special Report, No. 34.
10 *J.I.S.I.*, Jan., 1947, 51.
11 *J.I.S.I.*, July, 1947, 380.

On drawing, the work now being carried out has been undertaken to provide the background knowledge of the wire drawing process. It comprises a compilation and evaluation of existing information together with various investigations to determine the forces that are called into play in the drawing of wire, and the effects of varying conditions on the properties of drawn wire. For this purpose a prototype backpull drawing machine at Arthur Lee and Sons' works in Sheffield is being used. A bibliography of the literature of wire drawing is shortly to be published in the bibliographical series of the Iron and Steel Institute.

Experimental work on the influence of friction in drawing has been begun as has exploratory investigation of the effect of temperature on wire drawing.

In connection with this group of researches the Physics Department has developed a wire-tension meter for measuring the tension on wire while it is being drawn. For this purpose the principle is applied that the frequency of oscillation of a wire of constant length and constant mass per unit length is a function only of its tension. This is, in fact, the same principle as a musician employs in tuning his piano or violin.

Steel Castings Division

Work in connection with castings can also be considered under three main heads. Melting; foundry operations; moulding and refractory materials. On melting, the side-blown converter has received most attention, and much basic information is available.[12] This process is being studied further, in particular by the spectroscopic examination of the converter flame, with a view to obtaining fundamental data as to the course of the blow and also with a view to producing an improved method of control for the process. The work to date has shown variations in intensity of lines and bands associated with manganese and manganese oxide, as noted previously by other workers, and experiments are being carried ont with an instrument capable of recording the changes.

A series of researches is also proceeding on the freezing of steel, which range from theoretical investigations of the mechanism of freezing, to practical methods for preventing defects in castings that may arise during the setting of the steel, such as "burning on" and "hot tearing."

The whole field of the non-destructive testing of castings is receiving considerable attention and comparative tests with X-ray, Gamma-ray and supersonic methods indicate that the latter method, whilst being largely in a development stage in regard to its application to castings, shows great promise.

Another aspect of foundry operation which is being studied is silicosis in foundries, in which the Pathology Dept. of the University of Sheffield is co-operating with experiments on white rats, probably newcomers to the steel game. Some preliminary measurements of the concentration of dust particles in the atmosphere at various points in a foundry have been made, and this work is being greatly extended.

Study on moulding and refractory materials[13] is being carried out, and an apparently non-toxic moulding material is being exhaustively tested in practice, while work also goes forward on eliminating or reducing the need for linseed oil.[14]

A variety of materials used for monolithic converter linings is undergoing comparative trials with a view to establishing the properties required to give a satisfactory monolithic lining.

Plant Engineering Division

Before a summary is given of some of the more purely metallurgical work the engineering side of B.I.S.R.A.'s activities should be touched on. This is a comparatively new development, which is being undertaken along the usual lines of mechanical engineering; electrical engineering; civil engineering; fuel technology. The lines on which work is being carried out are indicated by a list of the present main objects of investigation:—

Design and Layout of Melting Shops.
Layout of Works, Buildings, Plant and Service.
Application of Gas Turbines for Blast-furnace Blowing.
Electric Overhead Travelling Cranes.
Economics of Locomotives, Rolling Stock and Traffic.
Fuel Distribution and Utilisation in Unit Processes.
Utilisation of Sensible Heat in Coke (e.g., Dry quenching).
Design of Mill Furnaces.
Servo mechanism and Remote Indicators.
O.H. Furnace Charging.
Metering of Liquid Fuel Flow.

Metallurgy (General) Division

On the metallurgical side the main sub-divisions of work now in hand are fundamental research on alloy steels, the mechanism and prevention of corrosion, the physics of metals, methods of analysis, and the development of new techniques for examination of the properties and behaviour of iron and steel.

The work on alloy steels has been transferred from the I.S.I. and is of long standing. The investigation into the factors contributing to the over-heating and burning of steel formed the basis of a successful conference at the Spring meeting of the Iron and Steel Institute,[15] and four of the five papers discussed were the direct outcome of these researches. Further work, particularly with respect to the influence of sulphur and the effect of mass and rate of cooling, is in hand, and a study of the influence of alloying elements on the properties of pure iron is being carried out at the N.P.L., together with an investigation of the sigma phase of iron-chromium-nickel alloys which is being investigated in connection with high-temperature embrittlement. Researches also continue on high and medium temperatures isothermal transformations.

The recent publication of "The Removal of Hydrogen from Steel"[16] illustrates the work that has been put into the study of hair line cracks, and this has reached the stage where preventive methods are being studied in works practice. Non-metallic inclusions and the detailed study of the physical properties of a whole series of alloy steels are other projects, which are receiving attention. Recent work at the N.P.L. on the determination of the physical constants of a number of alloy steels is reported in "The Physical Properties of a Series of Steels—Part II" in the Journal of the I.S.I. for last September.[17]

On the subject of the examination of methods of analysis, work is going forward under five main heads; blast-furnace raw materials; pig iron, carbon and low-alloy steels; other steels; spectrographic methods;

12 *J.I.S.I.*, Jan., 1947, 33.
13 *J.I.S.I.*, Feb., 1947, 235.
14 *Metallurgia*, July, 1946, 162.
15 *J.I.S.I.*, 1946, Vol. I.
16 *J.I.S.I.*, 1946, Vol. I.
17 *J.I.S.I.*, 1946, Vol. II.

physico-chemical methods. The last-named project covers investigation of absorptiometric methods, etc.[18]

In process of building up is an organisation for the study of metal physics, and work on the iron-nitrogen and iron-carbon-nitrogen systems is in progress. Another comparatively new development is the organisation of a "new techniques committee" whose task is concerned with the development of essentially new techniques for laboratory and works examination of the properties and behaviour of iron and steel in the solid state. So far study goes forward in four main directions: On mechanical methods, on magnetic and electric methods, on X ray and diffractions methods and on optical methods.

The work carried out by B.I.S.R.A. on brittle fracture in mild steel plates is a good example of researches stimulated by the failure of a technique insufficiently understood. The welding in certain ships made in foreign countries during the war failed, and representatives of all British organisations interested—governmental and Service departments, other research associations, the universities, Lloyds and numerous industrial laboratories—carried out various investigations culminating in a conference in October, 1945. As a result of intensive discussion under the chairmanship of Dr. (now Sir Andrew) McCance, who is chairman of the council of the British Iron and Steel Research Association, the lines of research necessary for ascertaining the cause and cure of the phenomenon of brittle fracture were indicated.

Subsequent researches at the works of Colvilles, Ltd., and at the University of Cambridge, established that brittle fracture was related to manganese content, plate thickness and the rate of cooling, the effect of the first factor being by far the greatest. Further work at Colvilles on small, closely controlled casts of steel made by the high-frequency process now seems to have established that for a given tensile strength an increase in the manganese—carbon ratio of mild steel has the desired effect of lowering the temperature range below which one must go before brittle fracture may take place. This effect is related to the fact that the increased ratio also tends to give a fine-grain steel. The latest work on this subject is able to conclude with a practical recommendation that for shipbuilding steels the manganese—carbon ratio should not be less than 3·0.

The results to date of this extensive series of experiments have been distributed to the members of the Association and participants in the original conference, and are shortly to be made available to a wider public through the technical press.

The ever-present subject of corrosion is, of course, still the object of much attention, which it is not easy to summarise. Inhibitive action of various substances; tests on the corrosion fatigue life of steel; exposures tests on protective coatings; study of the effects of low-alloy addition are some of the obvious main lines on which work is being carried out.[20]

On anti-fouling research, a review of work from 1942–44 has been published to indicate the lines on which B.I.S.R.A.'s Millport team is working both from the biological and chemical angles.[21] In this connection work goes forward in concert with the shipbuilding industry. It is also of interest that there has been made a preliminary survey of knowledge of the subject of the corrosion of iron and steel by industrial waters and the result will be summarised in a short popular brochure.

There are numerous other projects in hand, some of them of a more "purely" fundamental nature than those mentioned above. The Physics Laboratories in process of equipment for the Association in Battersea are already in partial operation, and here work goes forward on such subjects as:—

The measuring and theoretical interpretation of the physical properties of iron and steel in the liquid state, during the freezing process, and in the temperature range from freezing to atmospheric;

the investigation of the processes of heat flow and heat liberation, radiation from solids and flames;

the fundamental laws governing the flow and distribution of gases in furnace systems and also the dynamics of flow of liquid steel.

Such work is bound to bear on the never ceasing search for a continuous casting process for steel.

In general conclusion, then, it may be confidently stated that co-operative research in the iron and steel industry is a going concern. It cannot be too often remarked that B.I.S.R.A.'s purpose is to supplement and broaden the base of researches at individual firms' works and laboratories. It is not, and could never possibly be, to supersede them. The results of this continuous and painstaking "background" research are seldom spectacular. They are nevertheless essential to the wellbeing of the industry of which B.I.S.R.A. is a part.

18 *J.I.S.I.*, March, 1947, 373.
19 *Journal of the Oil and Colour Chemists' Association*, Feb., 1947.
20 *J.I.S.I.*, Jan., 1947, 27.
21 *J.I.S.I.*, 1946, Vol. II.

Celebrations to Mark the Jubilee of the Discovery of the Electron

THE Institute of Physics and the Physical Society in collaboration with the Institution of Electrical Engineers are arranging a series of lectures and other functions in London on September 25th and 26th next, to mark the jubilee of the discovery of the electron by J. J. Thomson. It is understood that some special lectures and meetings are also being arranged at various centres in the Dominions to mark this jubilee. Four special lectures have been arranged for the members of the three bodies collaborating in the celebrations. A lecture addressed to the non-scientific public by Sir Clifford Paterson, F.Inst.P., M.I.E.E., F.R.S., a past President of the Institute of Physics and of the Institution of Electrical Engineers will be given at the Central Hall, Westminster, at 7·30 p.m. on Thursday, September 25th, entitled "The Electron Liberated." The lecture is intended for a lay audience and will be illustrated by experiments and demonstrations. Admission is by ticket only, which may be obtained free of charge from the Institute of Physics, 47, Belgrave Square, S.W. 1. Requests should be accompanied by an addressed envelope.

Industrial Organisations and Universities have collaborated with the authorities at the Science Museum, South Kensington, in arranging a special exhibition, which will remain open for about three months. The exhibition is designed to show the principles underlying the applications of the many devices in which the electron plays an essential part, and to help the visitor to appreciate the important part these developments play in his daily activities. The exhibits will range from Thomson's original apparatus to the most modern developments, such as the electron microscope; many will be working. A handbook has been especially written by Mr. D. H. Follett, M.A., F.Inst. P., of the Science Museum.

British Non-Ferrous Metals Research Association

Recent Developments in Research Activities

By W. L. Hall, B.Sc., A.R.S.M., A.I.M., A.R.I.C.,

Chief Liaison Officer

Some account is given of the changes made in the objectives sought and of the new work in hand. Basic researches, of interest to the whole non-ferrous metals industry, are considered, while other work of a sectional character is discussed under separate headings. It is noteworthy that the research policy permits extension and adaptation to meet changing conditions.

An article which appeared in this Journal for September, 1946, described how the Research Committee structure of the Association had been modified to ensure that the research undertaken is that needed by the industry under prevailing conditions. The whole field of research appropriate to the B.N.F.M.R.A. was reviewed by the Research Board and its four Industry Research Committees towards the end of 1946 and, while many long standing items in the research programme continue as before, certain of the older researches have had their efforts directed towards more closely defined objectives and a number of entirely new research projects have been initiated.

In this article some account will be given of the changes which have been made and of the new work in hand. Although work has been started on all the new projects, it is too early to give more than a general statement of the type of work proposed in each case. No detailed mention will be made of the work of two important sections of the Association—namely, the Information Department and Library, and Liaison and Technical Enquiry Department, the services of which continue to be in great demand by members.

Researches which are of special interest to one section of the non-ferrous metals industry are grouped in this survey under headings corresponding to the appropriate industry research committees, but others, termed "basic" researches, are of interest to the whole industry and are considered separately.

BASIC RESEARCHES

Physics Department

The Association is fully alive to the need for providing facilities for the most up-to-date physical methods for examining metals and has recently been able to expand the Physics Department and to extend the range of equipment available. A Metropolitan-Vickers electron microscope has been installed and it is intended to examine thoroughly the metallurgical potentialities of the high magnifications which can be obtained by this instrument, so that the Association will be in a position to give thoroughly competent advice to its members on this matter and to exploit this tool in its own researches. At the moment a study is being made of existing replica techniques for examining solid surfaces, but early attention will be paid to the development of new techniques and of alternative methods of using the instrument for metallurgical work. Fig. 1 shows an electromicrograph of etch pits on super-purity aluminium, which was obtained by the anodic oxide replica technique.

Fig. 1.—Electromicrograph of etch pits in cast super-purity aluminium anodic film replica. Print magnification × 17,000. Reduced on reproduction to half size (linear).

The Association has already made good use of electron diffraction methods in its research, but has not hitherto possessed the necessary apparatus in its own laboratories. Advantage is now being taken of the fact that the high tension electrical supply required for electron diffraction is similar to that for the electron microscope, and an electron diffraction camera is being constructed in the Association's newly expanded and re-equipped workshops. As will be realised from what follows, the Association is at present tackling several problems where facilities for the examination of metal surfaces by this technique will be essential.

X-ray crystallographic methods are playing an increasingly important part in the research programme, almost every research receiving some help by the identification of phases or corrosion products, by the detection of internal strain due to cold work or precipitation, or by the assessment of orientation and of grain size. In addition to these established methods the newer techniques such as micro-radiography are employed where appropriate and a number of diffraction cameras have

been made to meet the special needs of metallurgical work.

The Association's long-standing research on the application of spectrographic methods to metallurgical analysis continues and work mentioned last year on the development of a suitable general purpose source unit is being followed up. The possibilities of multiplier photocells are being carefully investigated from the point of view of improving methods for the excitation of spectra, extending the scope of spectrographic analysis to both higher and lower alloy contents and the automatic electrical recording of spectra to replace the photographic plate and microphotometer.

Metal Finishing

Announcements have already been made in the technical press about the formation of a metal finishing section in the Association's research department. The Metal Finishing Laboratory is one of the new extensions to the Association's laboratory space and this, which is nearing completion, will include facilities for electroplating on a semi-commercial as well as on a laboratory scale, together with the necessary auxiliary equipment for degreasing, polishing, surface inspection, etc. It has already been decided that work on the electro-polishing of non-ferrous metals and on the adhesion of electrodeposits to aluminium and magnesium alloys shall receive first attention when experimental work is started. In addition to carrying out long-term researches such as these the metal finishing section will be able to handle technical enquiries on electro-plating and other allied metal finishing processes which are received from members.

Thermal Gradients in Castings

Progress has been made in the work on this subject which was mentioned in last year's review. The investigation is still only in its preliminary stages but experimental methods have been worked out which are suitable for measuring the temperature gradients which exist in solidifying metal. Some interesting results have already been reported to members.

COPPER, NICKEL AND THEIR ALLOYS

New Researches

Several new researches have been instituted of direct interest to this section of the industry. There is a lack of information on the copper-oxygen-phosphorus system and a fundamental investigation is in hand to provide the necessary data, which will be of value in connection with the production of high conductivity copper and will, it is hoped, throw light on the embrittlement sometimes reported in coppers in which both phosphorus and oxygen contents are less than critical values. During heat-treatment, certain copper-base alloys tend to form scales which are difficult to remove and a research on the surface oxidation and scaling of copper and copper-base alloys has been undertaken to obtain fundamental information on surface oxidation. It is hoped that the results will indicate how to avoid the formation of "difficult" scales or, if this should prove impossible, the most efficient methods of scale removal.

The researches mentioned in the last paragraph and most of the other new researches, are of the type known as "objective fundamental research" which is regarded as the rightful field of the Research Associations, but in view of the urgency for improving the electrical supply position as quickly as possible, the Copper and Nickel Industry Research Committee, with the approval of the Research Board, decided to carry out an *ad hoc* investigation to determine the most appropriate high conductivity copper for use as turbo-alternator rotor windings. Difficulties due to the present-day shortage of electrical generating plant are increased by the phenomenon known as "copper shortening" which may occur in large turbo-alternators due to the differential expansion of the copper windings on the steel rotor body and to the fact that centrifugal forces restrict such expansion at operating speeds. Serious "copper shortening" necessitates rewinding and the alternator may be out of commission for months. Materials of improved creep resistance appear to be called for and in addition to *ad hoc* creep tests on the materials now available, exploratory work will be undertaken on the possibility of developing new alloys of high electrical conductivity at the temperature of operation coupled with good creep resistance.

In recent years considerable interest has been aroused by the application of the results of research on degassing treatments for bronzes to the problems associated with the chill casting of tin-bronzes for subsequent working. As a contribution to a further study of outstanding problems, the Association is starting an investigation of the effect of impurities on the hot and cold working of tin-bronzes.

Casting

The Association's interest in sand casting of bronzes continues, and a paper published this year[1] deals with the practical aspects of the application of the results of recent work to the production of pressure-tight castings. A survey of industrial practice in the bronze foundries of members is being carried out by the Liaison Department to see how far the industry is finding it possible to apply the recommendations arising out of recent research and to collect information on problems which still require investigation. Meanwhile research work is continuing on the reaction between molten bronze and mould materials and atmospheres. This "mould-reaction", though undesirable at times, can be suitably controlled and exploited to prevent localised unsoundness in certain types of pressure-tight castings for which bronzes are commonly used.

Corrosion

A paper has been published[2] giving the results of certain soil corrosion tests of 10 years duration in which specimens of copper, lead and lead alloy pipes had been exposed to some seven types of soil in England and Scotland. Although no further work has been published in the year under review on the development of the corrosion resistant copper-nickel-iron alloys (for which patent protection has been obtained in the interest of members) work on the corrosion of metals used in condenser systems continues. As an example of the additional facilities now available in the corrosion section of the Research Department, Fig. 2 shows the latest form of the "Jet" test apparatus for examining the behaviour of alloys in rapidly moving aerated sea-water recently constructed in the Association's workshops. A pump in the lower section of the apparatus circulates

1 "Control of Bronze Melts for the Production of Pressure-tight Castings," W. A. Baker, *Institute of British Foundrymen, Advance Copy*, June, 1947.

2 "Corrosion of Copper, Lead and Lead Alloy Specimens after Burial in a number of Soils for Periods up to Ten Years," P. T. Gilbert, *J. Inst. Metals*, 1946, **73**, 139.

Fig. 2.—" Jet " test apparatus for accelerated corrosion tests in moving aerated sea-water.

aerated sea-water, through the distribution head at the top, to 24 jets immersed in sea-water in the stoneware tank. Specimens under test are located at a fixed distance from each jet.

Bismuth in Copper

An important paper[3] was recently published describing the work which has been in progress for a number of years on the effect of bismuth as an impurity in phosphorus-deoxidised copper. Remedial measures to overcome the deleterious effects of bismuth in copper and some copper-base alloys have been investigated and a patent has been granted to the Association (British Patent 581,903) for the elimination of bismuth embrittlement from copper and its alloys by the addition of lithium.

ALUMINIUM, MAGNESIUM AND THEIR ALLOYS

New Researches

The major new research in this section is on the recrystallisation of wrought aluminium alloys, the practical aspect of the research being concerned with the abnormal grain growth which is liable to occur with wrought aluminium alloys in certain forms as a result of solution heat-treatment or annealing. In addition, there is the new research on adhesion of electro-deposits already mentioned under the heading " Metal Finishing."

3 " Mechanism of the Embrittlement of Deoxidised Copper by Bismuth," E. Voce and A. P. C. Hallowes, *J. Inst. Metals*, 1947, **73**, 323.

Casting

Much of the Association's research on the casting of aluminium alloys is at present concerned with the " mould-reaction " which may occur in the sand casting of alloys containing appreciable quantities of magnesium or other reactive elements. The subject of grain refinement in both aluminium and magnesium alloys has been under investigation for some time under the guidance of research sub-committees dealing respectively with the casting of aluminium and of magnesium alloys. Recently these researches have been combined under a new sub-committee, the terms of reference of which embrace the investigation of the mechanism of grain refinement in light alloys in general and the work is continuing on fundamental lines.

The results of further work on hot tearing of aluminium alloys have recently been published.[4]

Stress Corrosion

Although no work has yet been published, the Association has been interested for several years in the phenomenon of stress corrosion in certain aluminium alloys. Investigations into the combined effect of cold work and heat-treatment on the susceptibility to stress corrosion of the aluminium—7% magnesium alloy were mentioned in the review of work which appeared in this Journal two years ago and a number of confidential reports have been issued to members. The scope of the work has now been extended to include more fundamental aspects of the phenomenon of stress corrosion and close contact with the other workers in this field is maintained, notably with Dr. U. R. Evans and his school at Cambridge University and with the Royal Aircraft Establishment, Farnborough. The Association is fortunate in having secured the services of Dr. Marie Gayler as a part-time consultant to advise the staff on precipitation phenomena in aluminium alloys in relation to stress corrosion behaviour. The team of investigators working on the stress corrosion of light alloys is also responsible for the Association's work on the intercrystalline failure of high tensile brasses.

Mechanical Properties

The Ministry of Supply (Aircraft) is sponsoring an investigation of the mechanical properties of aluminium alloys at elevated temperatures and this work continues.

4 " Note on the Effect of Dissolved Gas on the Hot Tearing of Aluminium Casting Alloys," D. C. G. Lees, *J. Inst. Metals*, 1947, **73**, 537.

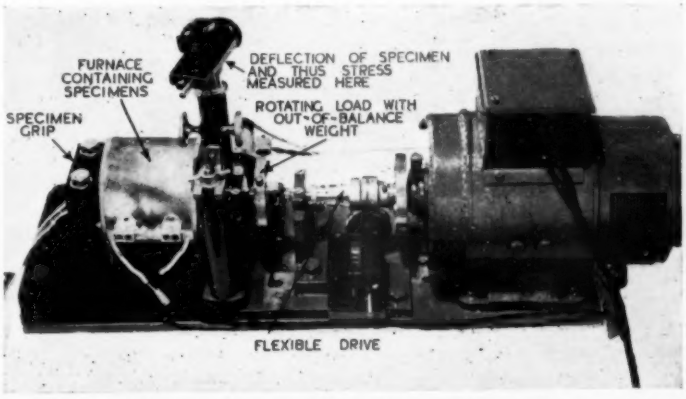

FURNACE CONTAINING SPECIMENS
DEFLECTION OF SPECIMEN AND THUS STRESS MEASURED HERE
SPECIMEN GRIP
ROTATING LOAD WITH OUT-OF-BALANCE WEIGHT
FLEXIBLE DRIVE

Fig. 3.—High-temperature rotating load fatigue testing machine.

A new rotating load fatigue testing machine has been developed specifically for this research to enable high temperature fatigue properties to be determined. A photograph of one of the units made in the Association's workshop is reproduced in Fig. 3. An investigation of the mechanical properties of certain magnesium-base alloys at sub-zero temperatures has been carried out, and the results have recently been published.[5]

LEAD, TIN AND THEIR ALLOYS

Chemical Lead

From time to time it has been suggested that the established " flash " and " aqua regia " tests for chemical lead are not thoroughly satisfactory as acceptance tests and though new research work has not yet been initiated on this subject, a survey is at present being made of industrial experience to determine if there is a problem appropriate for research by the Association.

Mechanical Properties

Research, designed to provide fundamental informatio

Research, designed to provide fundamental information on creep and fatigue properties of lead alloys necessary for the development of certain types of cable sheathing and of improved water pipes, continues and arrangements have been made to extrude alloys under experimental conditions in the Association's laboratories. These alloys will be used for a fundamental investigation of the creep characteristics of alloys having additional elements chosen from the point of view of their effect upon the metallographic structure. A paper has now been published[6] describing the part played by the Association in the development of the L-delay fuse during the war. It will be remembered that this fuse depended for its action on the deformation leading to fracture of a lead wire under controlled conditions and the paper mentioned above is the first published account of the metallurgical investigations which led to the successful development of this device.

ZINC AND GALVANISING

White Rust on Zinc

A new research project is in hand to study the formation of copious white corrosion products (white rust) which sometimes form on the surface of zinc and galvanised steel articles stored under conditions liable to cause condensation of moisture on the metal surfaces. Such conditions may arise for example in transit from this country to the tropics, and the research has a bearing among other things on the corrosion of galvanised articles exported from this country.

Galvanised Coatings

An account of the Association's work on the effect of additions to the galvanising bath has recently been published[7] and also a fundamental paper[8] on the use of the silver-silver chloride electrode in the electro-chemical investigation of corrosion problems. This particular technique has been applied in the Association's research work on the corrosion of galvanised coatings by hot domestic waters. It is considered that the electro-chemical aspects of this corrosion problem are now fairly well understood and attention is being paid to remedial measures.

Facilities for Solving Industrial Problems

These notes will have made it clear that a wide variety of work is undertaken by the B.N.F.M.R.A. and will have shown that, as is suitable for such an organisation, most of the researches have been planned to provide fundamental information which is needed for the solution of practical industrial difficulties. The research policy of a successful Research Association must not only be energetically pursued but must also be capable of extension and adaptation to meet changing conditions. It is hoped that this article has also given some idea of how these two conditions are being fulfilled.

It is impossible, within the relatively limited confines of the Association's staff to have available up-to-date industrial experience in all the many branches of the non-ferrous metal industry. The advice given by the members of the various advisory research committees, composed of technical men drawn from the staffs of member firms provides an invaluable means of bridging this gap. As an indication of the help received from members in this respect, it is interesting to note that persons representing some 78 members serve on these Research Committees.

The last twelve months has seen an expansion of the activities of the B.N.R.M.R.A. both as regards the amount of work in hand, laboratory space available, and the research staff employed. Such expansion has necessitated a considerable increase in the Association's expenditure on research, expenditure which, it is suggested is still relatively modest compared with the practical importance for industry of the results of research. This expansion, however, does not represent the limit of present plans since it is hoped to re-build war-damaged premises and introduce still further facilities to the research department.

It is gratifying to be able to report that many members have already increased their subscriptions by substantial amounts to meet the Association's increasing commitments. Others will no doubt follow their lead, and some further expansion of income can doubtless be expected from new members who are always welcome.

THE new edition of the McKechnie Catalogue of brass, bronze, nickel silver and copper extruded rods and sections is one of the most comprehensive that has been issued to the trade for some considerable time. It has been compiled by the Technical Staff, and contains details of no less than 46 alloys. In addition to listing and describing the various alloys, technical details of mechanical properties and chemical compositions are given together with suggestions for using the extrusions for particular processes.

Apart from a description of the extrusion process from raw material to bar, the catalogue contains seventeen technical tables which will be found invaluable to rod and bar users.

A feature of the catalogue is its extruded metal binding which facilitates handling, and preserves the life of the publication. It is certainly a new and novel use for extruded metal. In addition the production of this booklet is of a high order. It is published by McKechnie Brothers Ltd., Rotton Park Street, Birmingham, 16.

5 " Cast and Extruded Magnesium Alloys : Some Mechanical Tests at Room and Low Temperatures," D. E. Dineen and N. D. Benson, *Metal Industry*, 1947, **71**, 103.

6 " Investigations on Delay-action Fuses," J. McKeown, *Engineering*, 1947, **164**, 97.

7 " Some Fundamental Aspects of the Hot-dip Galvanising Process," W. L. Hall and L. Kenworthy, *Sheet Metal Industries*, 1947, **24**, 741.

8 " The Use of Silver-Silver Chloride Reference Electrodes in Dilute Solutions," P. T. Gilbert, *Faraday Society Reprint*, April, 1947.

The British Refractories Research Association

By A. E. Dodd, M.Sc., A.R.I.C.

Head of the Information Department, B.R.R.A.

Amongst the many activities of the above Association is a renewed attempt to understand more fully the behaviour of fireclay refractories when they are reheated. It forms part of a wider programme which is designed to conform to the need to understand so that difficulties can be overcome. Here it is referred to, in some detail, as an example of one type of investigation particularly suited to this Association.

SUBJECTS calling for scientific research vary considerably in their appeal to the research worker. Problems involving the design and use of new equipment based on the latest advances in physics or chemistry, or problems concerned with new types of raw material, cannot help but be more attractive than an investigation on some well-known feature of a common type of material. Yet such a line of investigation as the latter may, in point of fact, prove highly valuable to an industry.

A good example of this less scintillating type of research is a renewed attempt to understand more fully the behaviour of fireclay refractories when they are reheated. That raw fireclay shrinks on firing has been known since man first made a primitive crucible; that some fireclays may, at a certain temperature, expand rather than contract has also been known for many years. The causes of shrinkage have been adequately understood as being closely linked up with the vitrification process. Some of the chemical factors responsible for permanent expansion have also been appreciated. The possible occurrence of both effects at one time, however, renders the general problem more complex than might at first appear, and, since the determination of this tendency to volume change on reheating is basic to certain specifications, its importance is beyond dispute.

Three distinct processes can operate to cause a firebrick to expand on reheating: gas bloating, laminar splitting of large grains of clay or grog along lines of weakness between discrete layers, and growth of the solid material owing to some change in physical structure. For gas bloating to occur the material must contain substances that evolve gases when heated at a temperature when the body is vitrifying. Any clay that has bloated will be found to contain sealed pores; it is the evolution of gas within these pores at a temperature at which the body is softening, that causes the material to swell. The second variety of permanent expansion, laminar splitting, is not common in the fireclay refractories of this country; it is prevalent, however, among the American "flint clays." The third form of bloating is likewise uncommon, grain growth resulting from changes in the solid phase being likely to occur only in diaspore clays bonded with kaolinite material.

A careful examination of each of these factors on the basis of experimental work has shown that certain fireclays can be induced to expand or contract at will in the reheat test at 1,400° C., merely by varying the firing temperature and the fineness of grinding. A brick that expands when heated to, say, 1,400° C. will, if originally underfired, contract when heated above its firing temperature, then begin to expand as the temperature approaches 1,400° C. These movements occur consecutively in the reheat test, so that a brick that has been underfired may pass what is apparently a stringent after-contraction specification.

There is a widely held opinion that the nature of the atmosphere of the testing furnace may have an important influence on the result of the reheat test. This opinion derived from Mellor's early work in this country and Seger's work in Germany; both these authorities demonstrated by means of experiment that a fireclay refractory that shows permanent expansion on reheating in an oxidising atmosphere may contract in a reducing atmosphere. The reverse result has been observed, however, in the case of some American flint clays. Since the nature of the furnace atmosphere will influence the degree of vitrification, the softness of the heated fireclay, and the nature of the chemical reactions of gas-evolving impurities, it is evident that here again an apparently simple problem is, in fact, complex. Experiments have been carried out on twenty-two representative brands of British firebricks to see whether any generalisation is possible and it was found that the after-contraction under reducing conditions was usually greater than under oxidising conditions; several bricks that expanded in an oxidising atmosphere registered after-contractions under reducing conditions. In no case was an expansion produced or increased by the change from oxidising to reducing conditions. The magnitude of the observed effects was such as to prove that the extra shrinkage produced by testing in a reducing atmosphere may be sufficient to cause the rejection of a brick that would pass a specification, if tested in an oxidising atmosphere as laid down in the standard method of testing.

A research programme will normally conform to the rule "Understand—then Overcome." The investigation so far described provided sufficient basic information, taken in conjunction with the quite considerable amount of work that had gone before, both here and abroad, to give the requisite understanding. How overcome the difficulty? The problem was being examined, it should be remembered, from the standpoint of the user who wishes to have at hand a reliable method of testing. The troublesome after-expansions in the reheat test could be prevented by applying a small load to the specimen during the test, but the choice of a correct load would be particularly difficult to standardise. A load made small enough to avoid deforming some bricks excessively would be too small to prevent expansion in others. Experiments showed, in addition, that the variability of the material itself often hinders

comparison of the results obtained with and without an applied load.

The laboratory work has also confirmed the view that no reheat test carried out at a single temperature can provide all the information necessary to classify every type of firebrick. Tests carried out at 1,400° C. and at 1,250° C. on duplicate specimens would, in conjunction, be of more value than the present practice of carrying out a single test at 1,400° C. This double test would indicate which samples of firebrick pass the present test by contracting and expanding alternately.

This "utilitarian" piece of research has provided valuable data on which to consider a revision of a long-established testing procedure. It has achieved no spectacular result, but is an excellent example of one type of investigation which a research association must include in its programme. It has been reported here in some detail in pursuance of the policy adopted in earlier reviews for this journal. Other current work of immediate application to the metallurgical industries includes a continuation of the study of the chrome spinels reported last year, the examination of blown-out blast furnaces, the examination of the effect of ferrous oxide on a range of refractory materials, and other items. Through a joint committee with the British Iron and Steel Research Association, arrangements are being made to correlate the results of full-scale trials of chrome-magnesite refractories in open-hearth furnace roofs; it may be possible to give some of the results of this important work in the review for next year.

The British Cast Iron Research Association

By J. G. Pearce, M.Sc., M.I.Mech.E., M.I.E.E.

Chief developments in the metallurgy of cast iron since the founding of the Association have been the improvements in structure and mechanical properties effected by the use of alloy additions, culminating in the development of the acicular irons. Of considerable significance is the recent discovery of a method of producing cast iron in which the carbon is in the nodular form.

DURING the twelve months that have elapsed since the publication of the last review in METALLURGIA, the British Cast Iron Research Association has celebrated its Silver Jubilee, marking the completion of the first twenty-five years of its existence. The occasion coincided with the twenty-first anniversary of the appointment of the writer as Director.

The Association was founded in 1921, when the Department of Scientific and Industrial Research was four years old, and was installed at first in modest premises at St. Paul's Square, Birmingham, which, although subsequently enlarged on three occasions, were found to be inadequate for the Association's growing requirements, and in 1942 a move was made to the present accommodation at Bordesley Hall, a country residence near Alvechurch, situated about thirteen miles from Birmingham. The Scottish laboratories, opened in 1925, and extended in 1945, are located at the Foundry Technical Institute at Falkirk. A brief account of the growth and achievements of the Association during this time was given by the writer[1] early this year.

The quarter of a century which has passed since the inception of the Association has been a period of advance and progress in the foundry industry, and there seems no doubt that much of the credit must be assigned to the determined attack on research and development during this period, which, to mention one aspect only, has been largely responsible for the striking improvement in the status of cast iron.

Even at the close of the first World War, a cast iron with a tensile strength of 15–18 tons per square inch, while perhaps not considered unattainable, was thought to be exceptionally good, and beyond the normal reach of many foundries. To-day, cast irons can be produced commercially with tensile strengths ranging up to 30 tons per square inch and even higher. This gradual improvement has been reflected in the frequent adjustments and modifications made to the requirements embodied in specifications relating to cast iron and malleable cast iron published by the British Standards Institution.

The most important development in the metallurgy of cast iron during this period has undoubtedly been the improved structures, and the consequent raising of mechanical properties, which have resulted from the study of the effect of alloy additions such as nickel, chromium, molybdenum, copper, vanadium and titanium. The work on nickel alone revolutionised former ideas on the properties of cast iron, and led not only to improved engineering cast irons of the pearlitic type, but also to the introduction of a whole range of austenitic irons in which it was found possible to control the structural components to a considerable degree by the addition of nickel, copper and chromium. Such cast irons are now well established and are chiefly employed where resistance to wear, heat or corrosion is required. Martensitic irons have also been evolved.

A more recent development in the field of alloy additions has been the so-called acicular cast irons, which contain molybdenum, together with nickel and copper. These irons possess a shock-resistance of an order hitherto unknown and have a high resistance to stress, and their potentialities have not yet been fully explored.

An announcement was made at the luncheon commemorating the Silver Jubilee of the Association of a development which may well prove to be of more significance than any of the foregoing, and one which can scarcely fail to affect the status of ordinary cast iron. It was disclosed that it had been found possible to produce in the mould a cast iron in which the graphite structure, instead of being in the elongated flake form

1 Pearce, J. G. *Nature*, 1947, v. 159, January 11, p. 49.

commonly known hitherto, is in the nodular or spherical form resembling the temper carbon graphite associated with malleable cast iron. This structure, previously characteristic only of malleable cast iron, in which it is produced as the result of a lengthy annealing process, can be obtained by taking a relatively high carbon material, easily melted and poured, and subjecting it to a simple treatment. It should be made clear, however, that while the structure of the new material closely resembles that of malleable cast iron, its properties are vastly different. Thus, although the new material has a small measurable elongation, it does not share the ability of malleable cast iron to undergo considerable deformation and distortion prior to fracture. On the other hand, nodular cast iron can be produced with a strength and shock-resistance of an order previously associated with, and even exceeding that of the high-duty cast irons, but without the special compositions and treatments required for these irons.

In a melt of hematite pig iron of 3·9% carbon and 2·6% silicon, a standard 0·875 in. test bar gave in the untreated and treated states respectively, tensile strengths of 15·5 and 26·5 tons per square inch, and 29·4 and 47·9 tons per square inch transverse. The shock-resistance was increased from 13 to 47 ft.lbs. and the Brinell hardness from 185 to 215.

What may perhaps be regarded as the most significant feature of the new development is that it is more readily applicable to the medium and high, than to the low carbon and silicon irons, to those materials, in fact, which possess the best casting and machining properties and are least subject to shrinkage on cooling. It seems likely that while the new process will raise ordinary castings into another class mechanically, it will also provide a new point of departure for improving the present range of high-duty cast irons, the properties of which will no longer be determined by the flake graphite structure.

This development has emerged during a painstaking and long-term investigation into the nature and mechanism of graphite formation in cast iron, pursued over a number of years, and still in progress, in the conviction that only by a fuller understanding of the factors affecting graphite formation and the ability to control its form and distribution could any fundamental improvement be made in the properties of cast and malleable cast iron. Some of the results of this work will be found in a paper given to the Iron and Steel Institute this year by H. Morrogh and W. J. Williams,[2] "a paper which no future writer on the subject could afford to leave out of account," according to a contemporary opinion, in which a critical examination of the work of earlier contributors, in conjunction with the fresh experimental work carried out by the authors, enabled them to set out clearly those phenomena which require explanation and must conform with any comprehensive theory of graphitisation. The subject has been dealt with in less detail by the same writers in a further paper.[3] S. W. Palmer,[4] in a paper which may be considered relevant to the general theory of graphite formation, studied the influence of composition on the graphitisation and annealability of white cast iron, in the production of whiteheart and blackheart malleable cast iron, and gave an indication of the extent of the work yet to be carried out on the inter-relations of graphitisation and decarburisation in the malleable process and their probable dependence on manganese and sulphur content.

Another paper contributed to the Iron and Steel Institute by H. Morrogh[5] gives an account of the metallographic identification of the various forms in which tellurium, now a commercial addition, may occur in cast iron.

The majority of the investigations undertaken by the Association are nowadays reported in printed form in the Journal of Research and Development, a confidential publication which is circulated to all ordinary members. Thirty such reports have been published since the first issue of this Journal in August, 1945. A number of these are subsequently released by the Council for general publication.

The Association has participated in a number of visits to Germany in connection with the survey conducted by the British Intelligence Objectives Sub-Committee and three of the four reports have now been published.[6, 7, 8]

It will be seen that the year under review has been one of re-adjustment to peace-time requirements, with a consequent reversion of interest to research objectives of immediate concern to the industry.

The Association has always taken a keen interest in the education and training of foundry personnel, and in addition to its internal apprenticeship scheme, has made a practice of receiving trainees in its own laboratories. Other educational activities have included the organisation of short Study Courses which met with considerable success before the war, and it is hoped that it may be possible to arrange a similar course in the near future.

The British Foundry School, founded in 1935 to provide training for suitable candidates for future executive rank in the foundry industry, and accommodated at the Birmingham Central Technical College, was suspended on the outbreak of war. It will shortly be re-opened with the approval of the Ministry of Education and the support of the industry under the new title of the National Foundry College. It will be housed at the Wolverhampton and Staffordshire Technical College and will undertake the further education of students nominated by firms in the industry and others, who have already acquired practical experience in the foundry and whose general technical education is of appropriate standard. Emphasis will, therefore, be placed on the more advanced technical and theoretical aspects of foundry processes and both ferrous and non-ferrous practice will be covered in the curriculum.

2 Morrogh, H., and Williams, W. J. *Journal of the Iron and Steel Institute*, 1947, v. 155, March, pp. 321–371.

3 Ibid. Institute of British Foundrymen, Annual Meeting, 1947, Paper No. 875.

4 Palmer, S. W. Institute of British Foundrymen, Annual Meeting, 1947, Paper No. 876.

5 Morrogh, H. *Journal of the Iron and Steel Institute*, 1947, v. 155, January, pp. 21–28.

6 B.I.O.S. Final Report No. 676, Item No. 21, 101 pp. (German Metallurgical Research Laboratories) H.M.S.O.

7 B.I.O.S. Final Report No. 914, Item No. 21, 120 pp. (Manufacture of Light Castings) H.M.S.O.

8 B.I.O.S. Final Report No. 1237, Items Nos. 21 and 31, 119 pp. (Engineering Cast Iron) H.M.S.O.

Conference on Electron Microscopy

THE Seventh Conference on Electron Microscopy will be held in the Physics Department, University of Leeds, on September 16th to 17th. The proceedings will be concerned with the applications, rather than with the construction, of the electron microscope. The programme includes a session devoted to short contributions on work in progress, experimental difficulties and other matters which may not merit a full-length paper.

The British Welding Research Association

Planned Research in the Welding Industry

By F. A. Fox, M.Sc., D.Sc., F.I.M.,

Assistant Director, British Welding Research Association.

Recently organized under the aegis of the Department of Scientific and Industrial Research this Association has already given evidence that it is alive to the needs of a rapidly growing industry. This survey of the work in progress and contemplated shows that its services, in regard to both theory and practice, will be invaluable.

Introduction

DURING the recent war, there was a very great increase in the use of welding in all branches of engineering; the number of welders trebled, and the output of welding material increased four-fold. Even before the war, development was rapid, and one of the milestones in the history of the art was the holding of an International Conference in 1935 in which seventeen British Scientific and Technical Institutions participated, and to which 150 papers on the welding of iron and steel were contributed. In 1936, as a direct result of this Conference, the Welding Research Council was set up by the Institute of Welding, to investigate welding problems, and a programme of research was planned, covering a wide field. This body worked on a co-operative basis, a method which was—and is—very effective, but particularly so when the work was of an exploratory kind.

As the problems became more clearly defined, it was appreciated that many of them needed the continuous work of investigators, and sometimes the use of special equipment. In order to provide these research facilities and also to conform to the general government policy for the organisation of research associations, the Welding Research Council was incorporated in March 1946 as a Research Association under the ægis of the Department of Scientific and Industrial Research.

The Association sponsors work in external laboratories, such as the National Physical Laboratory and University laboratories and of other research associations and member firms. In addition, a small laboratory has been established at the London headquarters and another at Abington, near Cambridge. The former deals with metallurgical researches and the latter with researches involving the application of welding to engineering problems and also resistance welding. The Association is fortunate in having as Chairman of the Research Board, Dr. Baker, Professor of Mechanical Sciences at Cambridge University. In developing the research station at Abington, his help and advice are invaluable.

Abington Hall, when fully equipped, will provide about 16,000 square feet of laboratory space in brick buildings; additionally there are wooden huts in the grounds which also provide much needed space for the researches into welding application to full-size products.

An examination of the subject shows that welding may be considered under three headings: (*a*) the material to be joined and its behaviour in welding; (*b*) the methods of making the joint; and (*c*) the efficient application of welding to structures and components which require to be designed with a full knowledge of welding effects and properties. The first group is more or less metallurgical, the second has affinities with production engineering, and the third is closely concerned with the theory and practice of engineering in its many branches. Each of these groups may be subdivided (though such a subdivision may sometimes be rather artificial) according to the material involved—i.e., ferrous or non-ferrous. In practice, the non-ferrous classification may often be equated with "light-alloy."

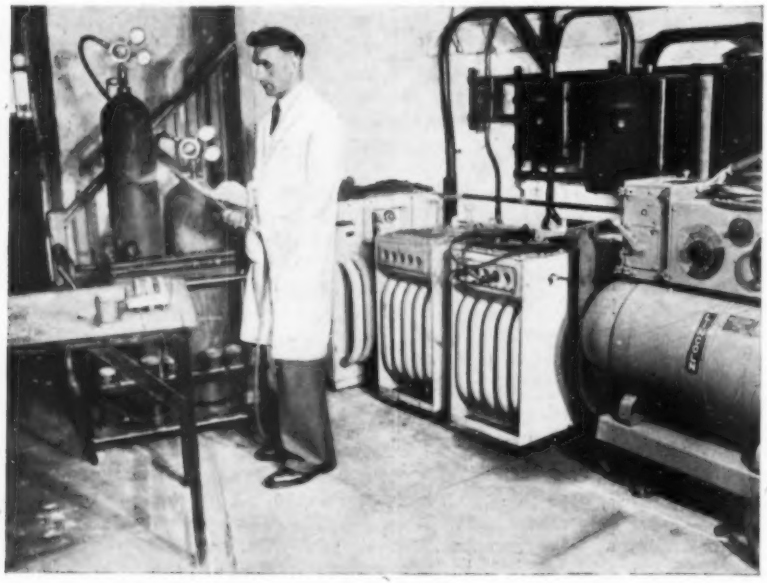


Fig. 1.—Part of Welding Laboratory at Park Crescent, London.

This then, provides six groupings of the work of the Association, and within each one the problems common to all research associations arise - how much effort should be devoted to short-term and *ad hoc* research, how much to data collection and codification, and how much to longer-term work of a more or less fundamental kind.

The following survey of the

Association's activities indicates the present balance between the various approaches just mentioned, as arrived at by the deliberations of the Association's Research Board and guiding committees, taking into account the available funds.

Fig. 2.—General view of the front of the B.W.R.A. establishment at Abington Hall, near Cambridge.

Metallurgy of Welding (Ferrous)

While the general metallurgy of the welding of mild steels is fairly well understood, there is much that is obscure about the behaviour of stronger ferrous alloys when welding is attempted; at the same time, it is important to try to reach a practical solution of the problem of finding materials of high strength which can readily be welded. The alloying elements which confer the improved mechanical properties are also liable to lead to the formation of cracks or other weld defects. Investigations made for the Association in the Metallurgy Department of the University of Birmingham have been concerned with the mechanism of the cracking; it has been shown, for example, that with some alloy steels, brittle transformation products are obtained on severe quenching from a critical temperature range in the region of 1,350° C., but that steel making procedure may much affect the steel's sensitivity to this critical temperature range. This line of work is being actively continued in both practical and theoretical fields.

A more empirical approach is also proceeding in a co-operative research in which a series of thirty alloy steels (with yield points in the range of 35–40 tons per square inch) are being tested for weldability, so as to yield indications of the influence of different alloying elements. Steels of promising composition will be selected for further examination in order to take into account the influence of steel-making procedure. The development of a test for weldability of steels has in itself been a subject for co-operative research, and practicable techniques have now been narrowed to three, which are the subject of further examination.

Weld Metal

A defect sometimes found when steel has been welded is that known as "fish eyes," the term being descriptive of the fractured surface when a sample is broken through the weld. A weld may be considered as analogous to a small casting made with very rapid melting and cooling rates and in contact with both gaseous products and molten slags; the possibility of a connection between the presence of "fish eyes" and critical distributions of non metallic inclusions and hydrogen in the weld metal is being studied for the Association at the National Physical Laboratory.

The quality of a weld deposit is considerably influenced by the constituents of the electrode coating. The viscosity of the slag formed during welding evidently has an important effect on the contour of the weld and on the escape of gases from the weld deposit. Investigatory work carried out at Sheffield University for the Association has indicated that the viscosity of the slag produced during welding may provide a means of classifying electrodes according to the purpose for which they should best be used.

Metallurgy of Welding (Non-Ferrous)

The use of light alloys in engineering structures is increasing, and in particular thicker sheets and heavier sections are being called for by the engineer. In order to make best use of their low density and good mechanical properties, it is most desirable to be able to join them by welding, and at the same time to reduce their strength as little as possible by the welding operation. In conjunction, therefore, with the aluminium industry the Association is embarking on a programme on the metallic arc welding of aluminium alloy plate; it is hoped to put through a similar programme on magnesium alloys, using the newly developed argonarc process.

The Association has co-operated during the past few years with the British Non-Ferrous Metals Research Association in investigating stronger aluminium alloys suitable for welding. Good properties in the intermediate strength range were found to be obtainable with an alloy containing 5% silicon and 2½% copper. It has also been found that good welds of high strength can be obtained from aluminium-magnesium alloys provided that a suitable degasification procedure is followed during manufacture and precautions are taken during welding. These special measures are necessary to avoid porosity, cracking and surface blistering due to gas reactions which are aggravated by the presence of small quantities of the alkaline earth metals.

Another problem receiving attention is concerned with the scatter in tensile strength results obtained on welded magnesium-manganese alloy sheet. Work for the Association in the laboratories of the British Non-Ferrous Metals Research Association has shown that the sharp strength variations are largely due to local grain-growth and to mis-alignment of the butting edges,

which seems to have a particularly important effect with these alloys.

Pressure Welding

Investigations on this process, which is of great potential value, have also been proceeding in co-operation with the British Non-Ferrous Metals Research Association. The conditions of temperature and pressure and the surface preparation necessary for the production of satisfactory joints have recently been established for a number of light alloys, and exploratory work carried out on other non-ferrous metals.

Methods of Making the Joint

The arc is clearly of fundamental importance in electric welding, and the characteristics of the lower power metallic arc have so far received little attention. Work is being done for the Association in the laboratories of the British Electrical Research Association to provide information on arc phenomena as they are related to welding behaviour, and for this purpose special electronic equipment has been installed and high-speed photography is being employed.

In the field of resistance welding, the Association's work is concerned with the fundamentals of spot welding and with single and multiple projection welding, especially with regard to those relations between the variables of current, pressure and time which lead to optimum welding conditions. The projection welding work is at present concerned with the welding of joints containing more than one projection, with particular reference to the question of weld quality and consistency of weld strength. The development of simple and accurate equipment for measuring current, pressure and time forms an important part of this side of the work, which has already led to the co-operative development of a mains-operated valve voltmeter for the measurement of secondary current.

Efficient Applications of Welding: Engineering Researches

The bases of design of steel structures such as are used for building contain elements which are mainly empirical; this empiricism is to a large extent, introduced by unknown factors at the joints and is particularly important where the constructions are of riveted manufacture. If the structures are welded, however, different conditions apply in that the joints are then rigid. Advanced engineering thought has recognised for some time that it should be possible to improve efficiency by evolving a theory of design based on the use of rigid structures which takes into account stress redistribution effects caused by temporary overloading and deformation of any part of the structure. In other words, considerations of "plastic design" which are attracting much attention at present are especially applicable to welded structures where the degree of "stress unloading" from one member to another is likely to be amenable to quantitative treatment. Professor Baker and his colleagues have been developing this general thesis for a number of years; as the work has led them to take an increased interest in the part played by welded constructions in tending towards greater design efficiency, it has been increasingly under B.W.R.A. ægis.

A study of the new factors introduced by welding into the design of structures entails considerable experimental research on the behaviour of welded constructions of all kinds, not only under static but also under dynamic loading. Investigations already carried out have explored the behaviour of beams and stanchions bent in single and double curvature, and it has been found that the load which a stanchion will safely carry may be several times that which would be permitted by the present conventional methods of design which do not take plastic deformation into account.

The early experiments were carried out with a loading frame in which the loads are applied to a model framework consisting of beams and stanchions all in one plane. A larger loading frame is now in use in which it is possible to load the stanchion also by beams coming in at right-angles to the framework. Preliminary work has indicated that rectangular portal frames designed by the plastic method may be 20% lighter than frames designed by conventional methods. Before the new method of design can gain general acceptance, it will be necessary to carry out tests on full-scale structures. It is intended that this full-scale testing, which will in all cases need to be carried to complete collapse, should be done at the Research Station at Abington.

In parallel with the main investigation there are also investigations on the plastic behaviour of rigid welded beam to stanchion connections, and on the load carrying capacity of welded battened stanchions.

Structures under Dynamic Loading

Considerable investigations have been carried out on the Continent and in America on the fatigue strength of welded joints in flat plates and rolled steel joists, but few have been made on full-scale structures. In order to provide information on fatigue behaviour, the Association has investigated welded structures by setting up vibrations in a member or frame and measuring the induced stresses from the amplitude and by strain gauges. The structure is supported in such a way that the vibrations are balanced within the testing unit and do not transmit large forces to the foundations. Pilot investigations have been carried out at the Engineering Laboratory, Cambridge, and three testing units are now installed at the Research Station at Abington, which has been located sufficiently far from a centre of habitation to avoid any possibility of trouble from noise or induced vibrations. Among the investigations in hand, or in course of preparation, are the following:—

(*a*) The effect of residual stresses and of stress-relieving on the fatigue endurance of welded steel constructions.

(*b*) The fatigue strength of spot welded light alloy structures.

(*c*) The fatigue behaviour of stiffened plate structures representative of welded ship construction.

These investigations are all in fields as yet almost unexplored, and will provide information which will enable welded structures to be designed for fatigue loading on a more logical basis than at present.

Fig. 3 shows a typical general arrangement of a fatigue test set up for welded constructions.

Stresses in Welded Pressure Vessels and Ancilliary Equipment

It is most desirable to explore the stress distribution in welded pressure vessels, so as to enable a determination to be made of allowable working stresses in the welded joints. Nearly three years ago, Messrs. Babcock and

Fig. 3. General arrangement of fatigue test on H-beam showing oscillator clamped to the beam. At "A" are limit switches which shut down the motor if the amplitude increases beyond a predetermined limit or in case of fracture; "B" is the automatic control contact. The driving shaft is hidden under a longitudinally split tube placed over the shaft for protection. A revolution counter is attached to the motor shaft. The white labels with crossed lines are used for the measurement of amplitude.

Wilcox kindly agreed to invite a B.W.R.A. Committee to act as joint supervisors with themselves of a research of this kind which they were carrying out on an all-welded mild steel boiler drum which was about 15 feet in length and 4 ft. 6 in. in diameter. This research is still going on, and in addition, equipment is now being installed at Abington for further test work of the same type. The results of these researches should be valuable in improving design efficiency in this specialised field and may also cast light on problems of inspection and safety of such constructions. Particular attention is being given to the stresses set up in the vicinity of nozzles, welded branch connections and other fittings on the shell of a pressure vessel. Additional pumping equipment to permit the use of test pressures up to 10,000 lbs. per square inch will be available at Abington Hall shortly.

Particular attention is also being given to the design and strength of welded pressure pipe connections, with special reference to oil installations, and a programme of work has been drawn up and a series of investigations put in hand to compare the behaviour of welded and seamless pipe bends. The bends to be tested are of 6 in. diameter 90° angle, and they will be subjected to pressure and to bending load conditions. In general, the measurements are to be made with electric resistance strain gauges attached both to the inside and to the outside of the bends; brittle lacquer coating is also being used for preliminary tests to determine the best location for the strain gauges in the main series of tests.

Preparation of Memoranda

In addition to the research work outlined above, the Association organises committees which meet to prepare recommendations or procedure memoranda of which the industry may stand in the need; work of this kind is often undertaken in collaboration with the British Standards Institution and the Institute of Welding. Several of these committees are very active and not a few publications which have been useful to the industry have been issued during the last few years.

A bibliography of those open publications for which the B.W.R.A. has been responsible during the last three years is appended. These are additional to the more numerous reports which are still confidential to the membership of the Association.

BRITISH WELDING RESEARCH ASSOCIATION—PUBLICATIONS AVAILABLE TO THE GENERAL PUBLIC, 1945, 1946, AND 1947.

	B.W.R.A. Ref. No.
Investigation into the behaviour of welded rigid frame structures. Fourth interim report: The behaviour of stanchions bent in single curvature. Illustrated. J. W. Roderick, with foreword by J. F. Baker. December, 1945.	R.24.
A moment distribution method for rigid frame steel structures loaded beyond the yield point. Illustrated. M. R. Horne. January, 1946.	R.25.
Fourth interim report on the investigation of the welding of ships' structures. Illustrated. J. Turnbull. January, 1946.	R.26.
The transfer of material temperature and stability in the electric welding arc. A resumé of published information. Illustrated. J. C. Needham. January, 1946.	R.27.
Pressure welding of light alloys without fusion Illustrated. R. F. Tylecote. January, 1946.	R.29.
Fatigue tests by the resonance vibration method on four welded H-beams. First interim report. Illustrated. A. L. Percival and R. Weck. January, 1947.	D.33.
Investigation into the behaviour of welded rigid frame structures. Third interim report: The behaviour of stanchions bent in single curvature. Illustrated. J. F. Baker and J. W. Roderick. July, 1942—*reprinted*, 1946.	R.18.
Argonarc Welding. (Collected Papers on Argonarc Welding presented to the Light Alloy Welding Symposium held by the B.W.R.A., in October, 1946.) May, 1947.	LM.3/28.
Recommended technique for making fillet welds in the downhand, vertical and overhead positions. Illustrated. *Revised*, March, 1946.	T.13A.
Recommended technique for making butt welds in mild steel plating in the downhand position with overhead back runs, and in the vertical and horizontal positions. Illustrated. November, 1945.	T.15.
Technique for the gas welding of magnesium alloys. May, 1946.	T.16.
Arc welded structural steelwork—1. Stanchions, bases, caps and joints. March, 1946.	T.17.
Technique for the gas welding of rolled aluminium and aluminium alloy castings, 2nd edition. Illustrated. May, 1942. *Reprinted*, 1946.	T.1.

The B.W.R.A. has recently begun to publish those of its reports which became available to the general public (i.e., after a period of circulation in which they are confidential to members only). Publication is made in a Journal entitled *Welding Research*. The contents list of the two issues so far published is given below.

Vol. I. No. 1. *April*, 1947.
The Relationship between Welding Conditions and the Strength and Quality of Single Spot Welds in Deep Drawing Quality Mild Steel Sheet in thicknesses from 20 to 14 S.W.G. A. J. Hipperson.
Arc Welded Structural Steelwork—Stanchion Bases, Caps and Joints.

Vol. I. No. 2. *June*, 1947.
Resumé of Reports on the Strength of Spot Welds in Mild Steel Sheet; Welded Stanchion Joints; Welded Constructions under Fatigue Loading Conditions and Heat Treatment of Welded Constructions.
Recommendations for the Heat Treatment of Welded Constructions in Mild Steel.
Fatigue Tests by the Resonance Vibration Method on Four Welded H-Beams.

MR. WANG MAN SUN, a British Council Chinese scholar, has been awarded the Brunton medal and £25 premium offered annually by Sheffield University to each of the two students who present the best original researches on a metallurgical subject during the session. Mr. Wang Man Sun, who became a British Council scholar in January, 1945, has recently had the D. Phil. degree conferred upon him, and he is now gaining practical experience in metallurgy as a student at the Sheffield mills of the English Steel Corporation.

Ship Welding Experiments

Activities of the Admiralty Shipwelding Committee

BRITISH shipbuilders have for some time been aware that for various reasons welding will become increasingly necessary, and that the day may not be far distant when it will completely displace riveting in the building of ships. A significant number of all welded ships have been or are being built in this country.

A great step forward was taken during the late war when the Americans used welding almost exclusively in the construction of their enormous emergency war programme, but this complete break with old-established practice has, not unnaturally, been attended by some failures, and these in turn have directed the attention of Naval Architects to the problems of why they occurred and how their recurrence can be avoided.

It is evident that the problem which faced the U.S.A. faces us too, and this was realised in 1943 when the Admiralty set up a Ship Welding Committee to investigate the problems arising from the employment of welding in ships' structures and to advise on methods for their solution.

A very complete outline of the work of the Committee has been given in a paper read before the Institution of Naval Architects in April, 1946, which is recorded in the Transactions of the Institution. Part of this investigation has been a series of experiments of a comparative nature, to find out exactly how far and in what respects riveted and welded ships differ in their behaviour on service, while other sections of the work have been concerned with the stresses induced by welding, and the characteristics of the steel used in welded ships.

The culmination of these years of research and investigation has been reached in the present experiments on the cargo ships *Clan Alpine* and *Ocean Vulcan*. These two steamers are almost identical in design, but with the significant difference that whereas the former is wholly riveted, the latter is almost entirely welded. The aim of the experiments is to establish the fundamental differences, if any, between riveted and welded construction, and at the same time to test out conventional theories of stress behaviour of hull structures on actual specimen ships. This latter aspect has never before been approached with such completeness as in the present experiments.

Briefly, the scope of the trials is as follows. The *Ocean Vulcan* has been trading across the North Atlantic during the past 15 months. During this time a party of investigators have, with the aid of the most up-to-date instruments, some of which have been speciall up-to-date instruments, some of which have been specially devised for the purpose, taken a complete record of all the various forces which the sea can impose on the ship's structure, in all sorts of weather. Some idea of the magnitude of the task can be gathered from the fact that nearly 1,000 instruments were installed, most of which were wired up to a central recording panel, which was photographed at half-second intervals by means of a cine-camera. During the periods when records were being taken, 850 readings were simultaneously photographed by each frame of the film, or 1,700 readings per second.

While these sea-trials of the *Ocean Vulcan* have been going on, her half-sister, the *Clan Alpine*, was subjected to a series of bending tests in still water, to establish the relation between the external forces and their effect on the structure. This has been done by flooding holds with water and measuring the strains produced on the hull. A whole cycle of varying bending forces has been imposed, and it is hoped that this cycle will cover the actual conditions as measured at sea, so that the corresponding strains likely to be met at sea can be deduced. In these trials the ship was sometimes given a heavy list, to simulate rolling, and sometimes a heavy trim, to simulate these attitudes in a seaway. Nearly 100,000 instrument readings have been made, and the gauges used are so delicate that strains of one-millionth of an inch per inch have been measured.

The *Ocean Vulcan* has completed her term of experiments at sea, and is now being prepared to undergo a repetition of the still water experiments which were carried out on the *Clan Alpine*.

A positive comparison of the effects of external forces on the two methods of construction will, therefore,be afforded. The quantity of data from both sea and still water experiments is astronomical, and it will be years, maybe, before a full analysis can be completed. Enough has been found, however, in a preliminary survey of the results to indicate that many new and hitherto unsuspected facts will emerge from these epoch-making experiments.

Concurrently with these investigations on actual ships scientific work under laboratory conditions has been carried out at Cambridge University and elsewhere to find out whether the " locked-up stresses " known to be caused by welding were harmful, and also to discover whether welding has any harmful effects on the steel. So far the investigations have given negative answers to both these questions, but it has been found that some steels, under certain combinations of low temperature and stress, are liable to fracture in a brittle manner. Fortunately these conditions, and these particular steels, are uncommon, but nevertheless steps are being taken to guard against their occurrence.

The Committee has been responsible for a number of important publications of a technical nature, among which may be mentioned the following :—

Memorandum M2 : " The Application of Electric Arc Welding to Ship Construction." H.M.S.O., 1946, 1/– net.
Memorandum M3 : " Repairs to Welded Ships." H.M.S.O., 1946, 9d. net.
Memorandum M4 : " The Examination of Arc Welds in the Shipyard." H.M.S.O., 1946, 1/– net.
Report R1 : " Report on Hogging and Sagging Tests on All-welded Tanker, M.V. *Neverita* H.M.S.O., 1946, 7s. 6d. net.

In addition the following papers on the work of the Committee have been read to Technical Institutions, and are recorded in their transactions.

1. " The Work of the Admiralty Ship Welding Committee," by Sir Amos L. Ayre and G. M. Boyd, Institution of Naval Architects, 1946.
2. " Structural Investigations in Still Water on the Welded Tanker, *Neverita*.
Part I.—Developments in instruments for measurement of Strain and Deflections in Ships Structures.
Part II.—The Tests and Their Results, by R. B. Shepheard, B.Sc. and James Turnbull, O.B.E., Institution of Naval Architects, 1946.
3. " Stresses and Deflections of two Cargo Liners During Launching," by K. J. Pascoe, M.A., Institution of Engineers and Shipbuilders in Scotland, 1946.
4. " Structural Investigations in Still Water on the Tanker, *Newcombia*, by F. B. Bull and R. B. Shepheard. North East Coast Institution of Engineers and Shipbuilders, 1947.

The Micro-Sclerometer: A New Micro-Hardness Tester*

By M. R. Girschig

A new micro-hardness tester is described which is designed for use on metallurgical microscopes and which possesses a number of interesting features. Brief reference is made to applications of the instrument and a comparison of hardness numbers obtained by different loads is given.

THE new micro-sclerometer is designed for use on metallurgical microscopes. After having chosen visually a suitable area for the impression the operator replaces the microscope objective by the micro-sclerometer, without displacing the specimen. The microscope stage with the specimen is then lowered into the spring-loaded diamond indenter. The axial displacement of the indenter which is measured by optical means is indicative of the load exerted. After raising of the stage, the micro-sclerometer is replaced by a high-power objective allowing measurement of the dimensions of the impression, being a function of the hardness.

Design

The micro-sclerometer is so compact that it can be interchanged with the objective of most of the commercial metallographic microscopes. It comprises a cantilever leaf spring 32 (Fig. 1), held at one end in the instrument body and linked with its other end to a universal joint at the lower part of a vertical spindle 6 which carries at its top the indenter 8 (ball or, in general, Vickers' diamond pyramid). The spring acts, therefore, on the indenter from below. Attached to spindle 6 is an external cone which fits into an internal cone seat 9 screwed into tube 2. This conical bearing ensures correct centering of the indenter on a vertical axis, but the cones are separated when the microscope stage is lowered and the specimen surface, contacting the indenter, displaces the spindle in vertical direction. The spindle 6 is now freely movable in the bore of cone 9 without being mechanically guided and only balanced between the indenter point in contact with the specimen and the spring linked to the lower joint (Fig. 2). Thus, very high sensitivity and a great accuracy are obtained, particularly due to the design of the leaf spring which perhaps may also be useful for other applications.

* Abstracted from M. R. Girschig. Un nouvel appareil de microdureté. Le "Microsclérometre L.C." paper read before the Soc. Francaise de Métallurgie, *Revue de Metallurgie*, Vol. 43, 1946, pp. 95.112.

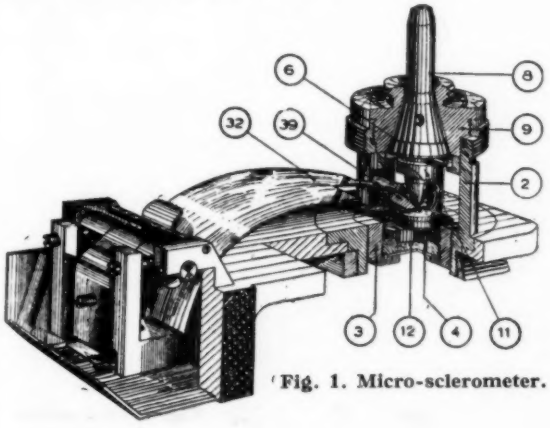


Fig. 1. Micro-sclerometer.

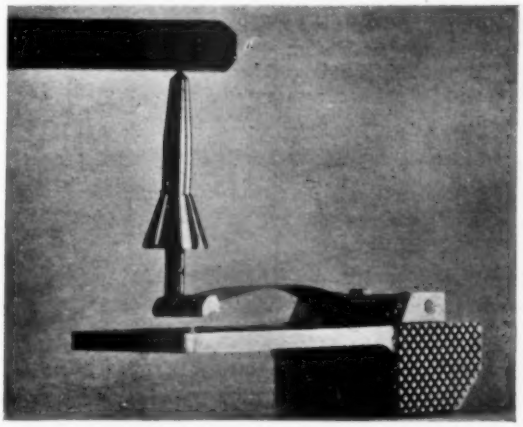


Fig. 2. Balancing spindle without mechanical guide.

A simple optical indicator allows precise locating of the spindle position. The indicator consists essentially of a concave spherical mirror 12 (Fig. 1) which is attached to the spindle by member 11. A double graticule 4, consisting of a glass slide of about 1 mm. thickness engraved on each face with squares of 0·2 mm. side length, is fixed to the instrument body. The upper graticule of the slide 4, is in the focus of mirror 12, in the original position of the micro-sclerometer (when the two cones are in contact). In this position, a clear image of the upper graticule is visible in the eye-piece. The image disappears when the spindle with the indenter is displaced by lowering the stage with the specimen. As soon as the image of the lower graticule appears in the eye-piece, the operator arrests the movement of the stage. Thus the displacement of the spindle is located and known within 0·05 mm., and the load can be determined with high accuracy.

The design of the micro-sclerometer as described above is based on the supposition that the spindle with the indenter maintains its correct vertical position without any guide, in order to obtain a perfect impression and to avoid friction at the centering cones and gliding of the indenter on the specimen surface. The spindle can only maintain its vertical position during its displacement if the spring acts absolutely perpendicular to the specimen surface. Otherwise the correct position has to be obtained by adjusting the members which anchor the spring in the instrument body.

Load Range of the Micro-sclerometer. Anchorage and Adjustment of the Springs

The leaf spring of the micro-sclerometer is simply a thin straight steel blade which forms a natural curve on the instrument depending only on the anchorage angle and the length of the blade. By keeping these two values constant, but altering the width and thickness of the blades, a series of interchangeable leaf springs can be designed for different loads. The commercial apparatus is provided with 5 springs for loads of 10, 30, 100, 300 and 1,000 grams ; thus a compact arrangement of very high sensitivity is obtained. The height of the bent leaf spring is 21 mm., the highest point rising by 0·7 mm. when the load is increased by 1%. As the optical indicator allows locating of the spindle within about 0·05 mm., the load on the diamond can be determined within an accuracy of about 1%.

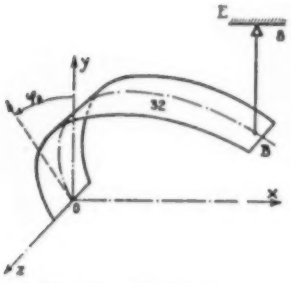


Fig. 3.—Leaf spring.

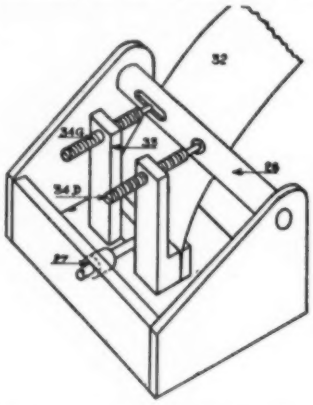


Fig. 4.—Anchorage of leaf spring.

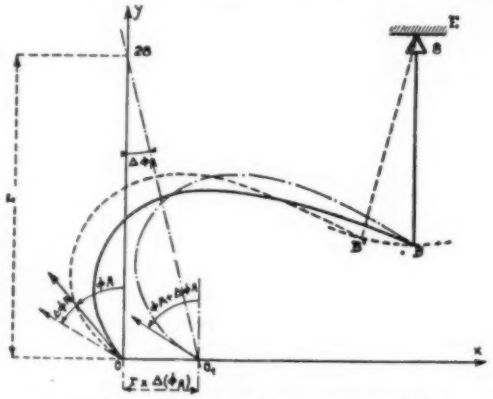


Fig. 5.—Adjusting anchorage angle.

For the adjustment, mentioned in the previous paragraph, the leaf spring can be rotated around axes OZ and OY (Fig. 3). The spring is riveted to plate 33 (Fig. 4),which carries two screws 34D and 34G. By the spring action, plate 33 abuts against three points of the instrument body. One, 27, is fixed, and the other two are determined by the position of the two screws 34D and 34G which lodge themselves in a straight slot and a conical hole of the fixed bar 26. Rotation around the two axes is then attained by adjusting these two screws.

A third adjustment is required to modify within limits the pressure exerted by the spring. For this purpose, the anchorage angle is altered by rotating anchorage plate 33 around axis 28 (Figs. 5 and 6). This is attained by letting abut plate 33 not directly on the instrument body but on the cheek plate 26, rotating around spindle 28 which is fixed to the instrument body at the distance r from O. By adjusting screw 25, the position of cheek plate 26 is affected and hence the pressure on the diamond controlled within limits ± 5%.

In order to facilitate changing of the springs, screw 25 is fixed in member 24 which rotates itself around axis 28 and which is held in position by hook 19. When the hook is released, the anchorage device pivots around axis 28, relieving the spring which can then be removed easily in horizontal direction towards the rear of the instrument. Another spring can be inserted correspondingly. All parts of the anchorage device are thus held together by the spring action, and cannot be displaced accidentally.

1 This relation is obtained by differentiation of the main equation $H = 1{\cdot}8544 \times P/d^2$, resulting in $\frac{\Delta H}{H} \leq 2\frac{\Delta d}{d} + \frac{\Delta P}{P}$

Calibrating the Load

In order to verify at any time the applied load, an additional calibrating device (Fig. 7) can be attached to the microscope stage. The device consists essentially of an astatic balance, the beam 5 of which carries at its end a centering block 6 which rests on the diamond indenter. The spring action is balanced by weights on the centering block. To avoid horizontal displacement, the beam is connected with the body of the device by a very thin horizontal metal spring 13 (0·08 mm. thick). An excess load of 0·05 gr. lowers the beam already to its abutment. The calibrating is carried out by adjusting screw 25 of the micro-sclerometer until a clear image of the lower graticule is observed in the microscope eye-piece. The spring action corresponds then exactly to the weight on the centering block.

Accuracy of Device

After careful investigations into the effect of cold working during indenting, the effect of different loads, the spacing of the indentations, and the influence of the number of indentations on the accuracy of the results, it is concluded that the total relative error in the hardness number $\frac{\Delta H}{H}$ is the sum of two ratios[1].

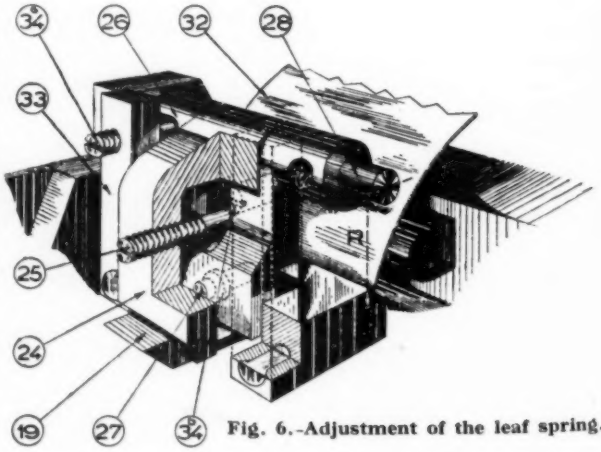


Fig. 6.-Adjustment of the leaf spring.

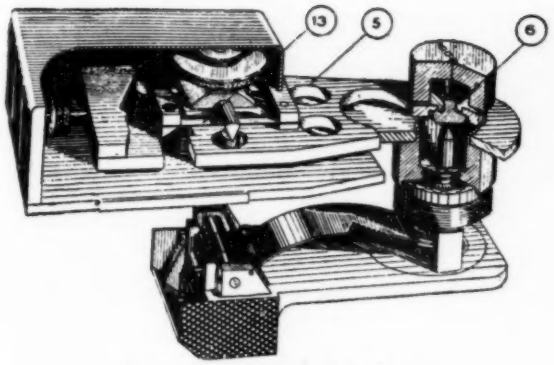


Fig. 7.—Load calibrating device.

(*a*) One, $2 \times \frac{\Delta d}{d}$ is dependent on the microscope used for measuring the diagonal d of the impression ;

(*b*) the other one, $\frac{\Delta P}{P}$ depends only on the precision with which the load P can be determined in the micro-sclerometer.

If a powerful microscope is used, the relative error under the best conditions will be $\frac{\Delta d}{d} \geq \frac{1}{200}$

TABLE I.—MEASURING OF THE DIAGONAL *D* OF VICKERS IMPRESSIONS WITH HIGH QUALITY OBJECTIVES.

	Apochromatic 75 ×	Achromatic 45 ×	Achromatic 15 ×
Numerical Aperture	0·95	0·65	0·25
Maximum field (microns) ..	100	200	500
Resolving power (microns) ..	0·32	0·47	1·22
Absolute error *d* measuring the impression diagonal (micron)	0·64	0·94	2·44
Relative error $\frac{\Delta d}{d}$ .. .. (corresponding minimum)	$\frac{0·64}{100} = \frac{1·28}{200}$	$\frac{0·94}{200}$	$\frac{2·44}{500} = \frac{0·98}{200}$

It is assumed that the real error $\frac{\Delta P}{P}$ introduced is always smaller than the error $2 \times \frac{\Delta d}{d}$, assumed that $\frac{\Delta P}{P} \leq 2 \times \frac{\Delta d}{d} = \frac{1}{100}$

This accuracy over the whole range of loads is within the limits of ± 0·5%.

The errors in the hardness number H will nearly always be caused in the measuring of the impression diagonals, and under the best conditions the accuracy in micro-hardness obtained with the micro-sclerometer will be 1·5%, unless the impressions are too small to be measured accurately with the best microscope.

Choice of Load

In order to exclude relative errors in measuring as far as possible, the higher loads (300 or 1,000 gr.) should be generally used. The following instances require small loads :—

Specimens of very small dimensions, or of small radii of curvature (watch components, foils ; the thickness of the specimen must be greater than the diagonal of the impression, and, in a horizontal plane, a circle circumscribed around the impression must not reach the borders of the specimen). Hard and brittle substances (glass, enamel, minerals). Individual micrographic constituents of alloys.

The Influence of Inertia of the Moving Parts

Theoretical and practical considerations show that the influence of the inertia due to too high a speed of the stage when it is lowered, is the more pronounced :—

(*a*) the higher the hardness ;

(*b*) the smaller the load.

Charts developed by the author permit to read the maximum speed which keeps the error in hardness numbers below 1%.

For instance, a specimen of a D.P. Hardness (Vickers) of 1,000 kg./sq. mm., at loads of 10 gr., 30 gr., 100 gr., 300 gr., 1,000 gr., requires speeds of less than 0·07, 0·104, 0·38, 0·88, 2·2 mm./sec.

Such low speeds are easily obtainable by using the fine focussing screw of the microscope.

Comparison of Hardness Numbers Obtained by Different Loads

The D.P. hardness number (Vickers) of homogeneous material defined by the main-equation $H = \frac{1·8544 \times P}{d_2}$ (kg./sq. mm.) is generally independent of the applied load, if this varies between 5 and 120 kg. If very small

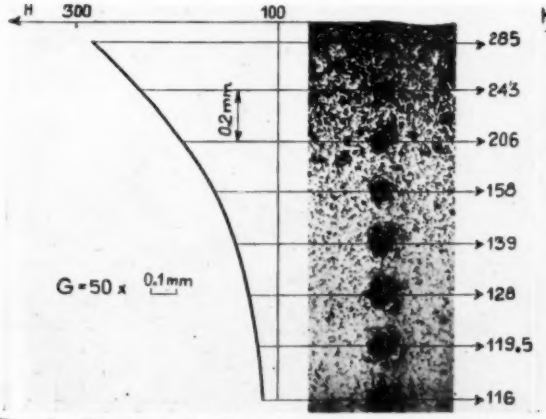


Fig. 8.—Hardness in the surface layer of case-hardened steel (not quenched) depending on distance from surface. Load 1,000 gr., mag. × 50.

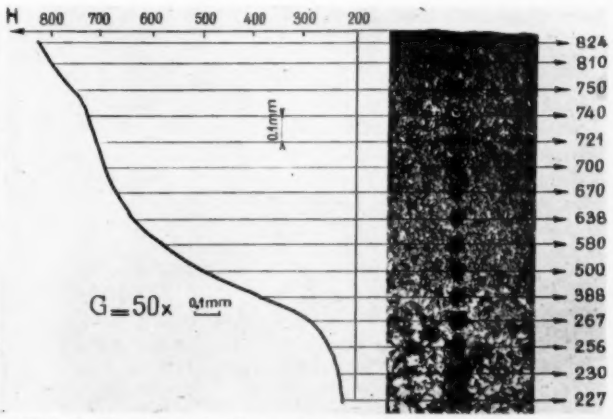


Fig. 9. Hardness in the surface layer of quenched steel, conditions as in Fig. 8.

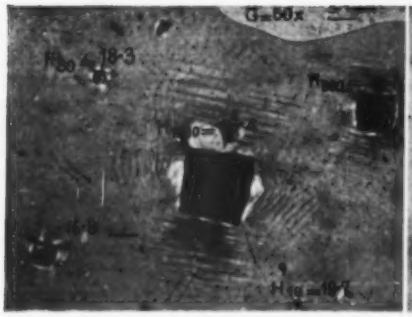


Fig. 10.—Impressions in Aluminium crystal under 10, 30, 100, 300 and 1,000 gr. load, mag. × 50.

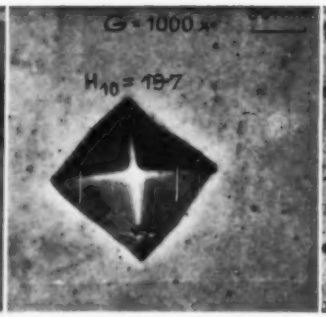


Fig. 11.—Impression in Aluminium crystal, load 10 gr., mag. × 1,000.

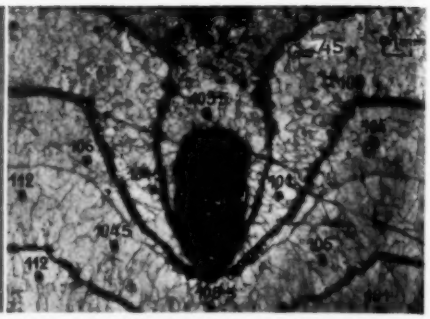


Fig. 12.—Impressions in electro-deposited iron layers, load 100 g., mag. ×45.

loads are applied, however, this is not true any longer. Instead, it is observed that for homogeneous material the quotient $\frac{P}{d^n} = a$ remains constant for a wide range of loads (Meyer).

The index n and the constant a are characteristic of the investigated material, n being in the neighbourhood of 2.

It is usual to base the Vickers hardness on the main equation rather than on the values for a and n of a specific material, which are more difficult to determine. It is essential, however, that the applied is then stated as well as the hardness number, if the load is small.

The knowledge of the index n of Meyer for a specific material permits to compare the Vickers hardness numbers obtained under different loads.

If Hp is the Vickers hardness under the load P, and Hpo the Vickers hardness of the same specimen under the load Po, the following equation is obtained :—

$$H_p = H_{po} \times \left(\frac{P_o}{P}\right) \frac{2^{-n}}{n}$$

which shows that the hardness number increases with decreasing load if n is lower than 2. The inverse conclusion is reached if n is higher than 2.

Table II gives, as practical example, the hardness variation under different loads for pure aluminium (electro-polished). Table III shows the Vickers hardness numbers for some pure electro-polished metals under 100 gr. load, and the index n for loads under 1 kg.

TABLE II.—D.P. HARDNESS VARIATION (VICKERS) FOR A SPECIMEN OF PURE (ELECTRO-POLISHED) ALUMINIUM UNDER DIFFERENT LOADS.

P	10 g.	30 g.	100 g.	300 g.	1,000 g.
Hp	19·7	18·3	16·8	16·3	15·4
$Hp/H\ 1{,}000$	1·28	1·19	1·09	1·06	1
$\left(\frac{1{,}000}{P}\right)^{\frac{2-n}{n}}$	1·26	1·192	1·12	1·062	1

TABLE III.—D.P. HARDNESS NUMBER (VICKERS) AND INDEX N (MEYER) FOR PURE ELECTRO-POLISHED METALS. LOAD 100 gr.

	H_{100} (kg./sq. mm.)	n (for loads under 1 kg.)
Aluminium	16·8	1·90
Iron	87·6	2·00
Copper	63·0	2·20
Lead	4·9	1·80
Tin	6·8	1·80
Nickel	143·0	2·15

Examples of Application

In the following, some examples are given illustrating the application of the micro-sclerometer. No attempt is made here to investigate systematically the phenomena involved.

Figs. 8 and 9 illustrate (at 50 × mag.) an investigation into the hardness variation in the surface layer of case-hardened steel. A load of 1,000 grams was chosen to exclude the influence of the grain distribution in the steel. The two curves show how the hardness number depends on the distance from the surface of a quenched and a not-quenched specimen. Although the highest

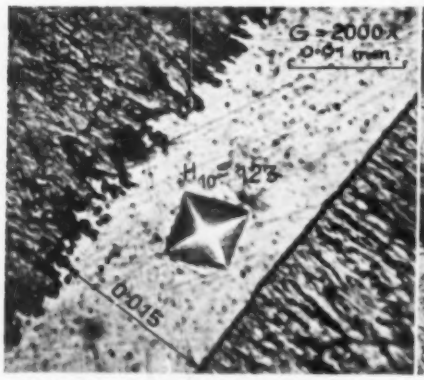
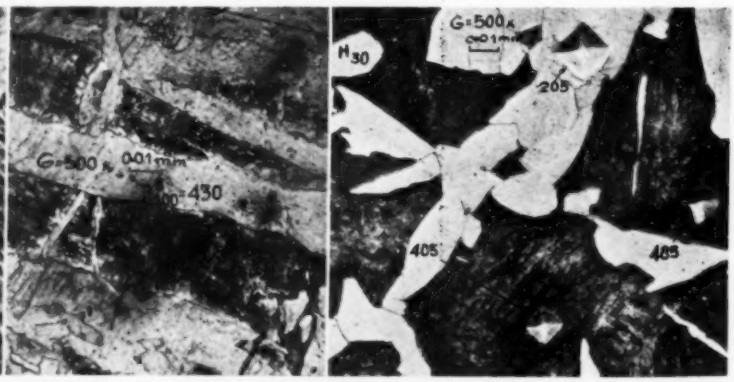


Fig. 13.—Impression in electro-deposited copper layer, load 10 gr., mag. × 2000.



Figs. 14 & 15.—Impressions in different constituent (bainite and ferrite), of not completely quenched steel, load 30 gr., mag. × 500.

load was applied, the impressions are still very closely spaced (0·2 and 0·1 mm.), permitting a corresponding thorough analysis of the hardness distribution in the surface layers.

Fig. 10 demonstrates the influence of the load on the hardness number obtained. This illustration shows, at 50 × mag., impressions in the same electro-polished aluminium crystal under the 5 standard loads of 10, 30, 100, 300 and 1,000 gr. The impression diagonals form a sequence similar to the series $\sqrt{10}$, the ratio of the impression areas under the smallest and highest loads (10 and 1,000 gr.) being 1 : 100.

Fig. 11 shows at 1,000 × magnification the well-defined impression obtained under the smallest standard load of 10 gr.

Figs. 12 and 13 relate to the investigation into the hardness of iron layers electro-deposited successively on the same core, but under different experimental conditions, in order to determine the optimum conditions for the electrolysis. The impressions are placed near a considerable defect in the specimen. The different iron layers are separated by thin (15 microns) electro-deposited copper layers, the hardness of which was determined under a load of 10 gr. (Fig. 13).

Figs. 14 and 15 finally demonstrate the possibility of determining the micro-hardness of different constituents of the same micrographic section, in the special case of bainite and ferrite in a partly hardened steel which was not completely quenched. The mean hardness numbers (Vickers) of the two constituents were 205 and 485. It could be observed that the impressions appeared better defined when the micrographic etching was less prolonged. Etching was, therefore, reduced to the minimum necessary to show the boundaries of the constituents.

A New Method of Non-Destructive Spot-Weld Testing for Stainless Steels

By A. M. Armour

(*Research Department of the Metropolitan-Vickers Electrical Co. Ltd.*)

Several methods are adopted for the routine examination of spot welds in austenitic steel sheets. A new non-destructive methcd has been developed which is quick, simple and reliable. This new inspection technique is described.

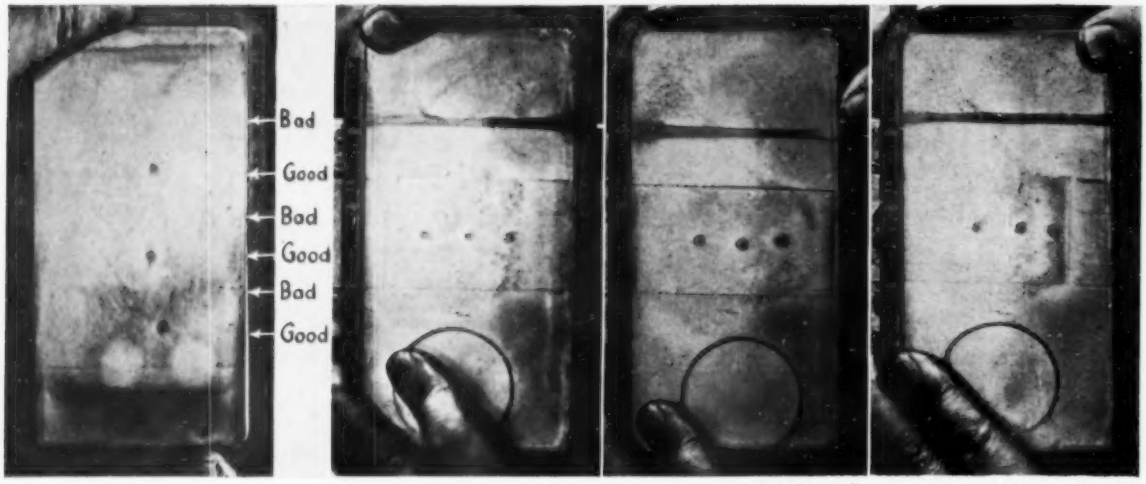
ARISING out of the need for some quick and reliable method of testing spot-welds in austenitic steel sheets, a new inspection technique has been devised by the Research Department of the Metropolitan-Vickers Electrical Co. Ltd. Hitherto, the test methods used have been (*a*) tests to destruction on so-called representative samples, and (*b*) X-ray examination of routine welds. In the first case, a weld was considered satisfactory if it pulled its slug out of one of the sheets, thus leaving a hole as the sheets were torn apart; it was regarded as unsatisfactory if it broke at the welded interface. In the second or radiographic method, the actual routine welds (not samples) were X-ray photographed, and the radiographs were examined for signs of a small cavity, with or without associated cracks, within the area of the weld spot. If this cavity were shown on the film, the weld was regarded as sound; if not, as not sound. Typical radiographs are shown in Fig. 7. Welds showing cavities in the spot always proved to be the strongest welds on destructive test afterwards, and this was thought to be a pointer to what was happening in the spot during the welding operation. It was felt that a weld taken to a sufficiently high temperature to give good fusion was also more likely to form a cavity on cooling than one that did not reach such a temperature and so resulted in a poorer weld; thus the cavity shown by X-ray test became the tell-tale of the spot's thermal history and was accepted as a reliable method of non-destructive

Fig. 1.—Metroflux captive fluid detector cells and permanent magnets.

Fig. 4.—Magnetic testing of spot-welds on a combustion chamber.

Fig. 2.—Sample spot-welds revealed by "white-spot" method of magnetic testing.

Fig. 3.—Metroflux detector and magnet applied to a typical specimen.



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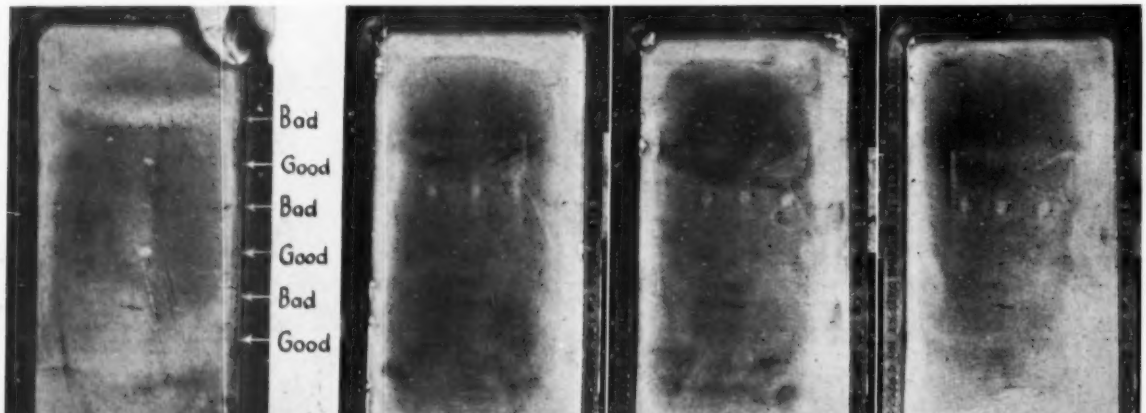
Six spots (alternate high and low current settings). *Three spots (normal current).* *Three spots (high current).* *Three spots (high current).*

Fig. 5. " Black-spot " testing technique applied to good and bad welds.

examination. Electrical resistance tests on spots, which were also tried, were found to be unreliable and difficult to apply.

The disadvantages of the radiographic test method are its costliness and the time required to obtain a result. Previous research work on chromium-nickel stainless material in other connections suggested that the rather special magnetic properties of this material might be used to provide a criterion of spot-weld temperature history. For instance, austenitic material stressed by shearing, working, rolling, and so on, was known to change its magnetic properties, and it was also known that heat treatment produced magnetic changes. In order to investigate the matter, stainless steel sheets were spot-welded together in large numbers and with different settings of the welding machine so as to give welds ranging from very good to very poor fusion. These were magnetically, radiographically, and destructively examined, and good correlation was found. It was noted that the better the weld the greater the change in magnetic permeability at the spots: the permeability was always increased by welding, and this change was appreciable in good welds and very small in bad welds. The magnetic properties were measured by means of a differential inductance bridge working at 50 c.p.s. This, however, was felt to be an unsatisfactory device to put into a sheet-fabricating shop, as great care was necessary to obtain consistent results.

So far, it had been established that a quickly obtained magnetic criterion of weld-spot thermal history could be relied upon to check with proof tests and radiographic tests, but the method of applying this magnet test called for little less skill than the radiographic method.



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Six spots (alternate low and high current settings). *Three spots (normal current).* *Three spots (high current).* *Three spots (high current).*

Fig. 6. " White-spot " testing technique applied to good and bad welds.

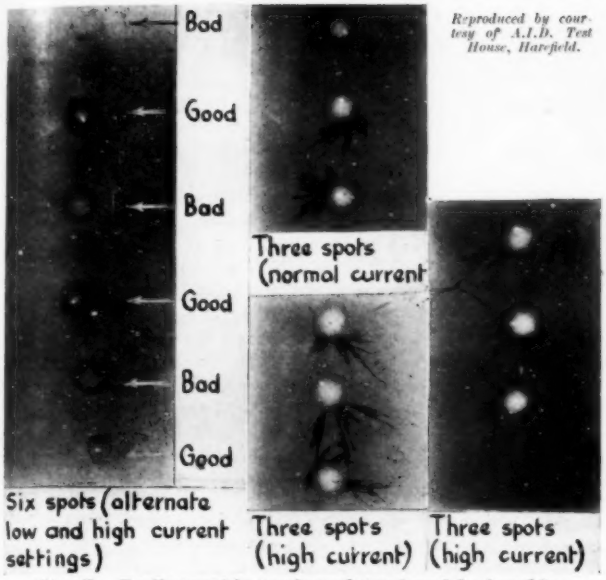

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Fig. 7.—Radiographic testing of good and bad welds.

Hence search was made for a magnetic detector that would be capable of responding to small local changes in permeability while being simple to apply to welds in difficult situations. The Metroflux captive-fluid magnetic detector cell (British Patent No. 439324) developed by the Metropolitan-Vickers Research Department provided just the combination of simplicity, sensitivity and flexibility that was needed. This cell, examples of which are shown in Fig. 1, consists of a transparent plastic moulding, which can be of any convenient size or shape, in the form of a shallow dish with a thin diaphragm forming a back that is usually opaque and white. The cell is sealed off and contains a small quantity of black magnetic fluid made up of minute magnetised particles suspended in a light oil. If such a detector is shaken well so as to disperse the magnetic particles through the oil and is laid down on the magnetised sheet face containing a spot weld, the magnetic particles will swim to the magnetic spot and reveal it as a particle pattern on the white diaphragm, as shown in Fig. 2. This will only occur if the magnetic properties at the spot differ appreciably from those of the parent sheet. Thus the detector only shows up those spots that have reached a high enough temperature during welding to produce satisfactory welds. Examples are seen in Figs. 3, 5 and 6.

In some welded spots the residual flux is sufficient to produce these particle patterns, but results are achieved with far greater speed and certainty if some external magnetisation is applied to the sheet simultaneously with the captive fluid detector. For this purpose, permanent magnets or electromagnets can be used, depending upon the accessibility of the spots to be checked. Fig. 4 shows the detector being used in conjunction with a permanent magnet on the spot-welds on a gas-turbine combustion chamber. For inaccessible places where it is impossible to place the detector cell so that a particle pattern can be observed, free magnetic fluid of rather greater than normal concentration should be sprayed over the spots; this will tend to show the particle patterns on the surface of the metal, but it is not as satisfactory as the captive-fluid method.

As a result of extensive use of the magnetic method of spot-weld examination in the Metropolitan-Vickers works, two types of particle pattern have become known. These depend upon the direction in which the external magnetisation is made to traverse the spots. In the "black spot" technique the flux from the exciting magnet is made to flow axially up the spot (see Fig. 5), normal to the sheet surface and into the detector cell. The more permeable spots tend to act as magnetic extensions to the exciting magnet and so draw the particles to them in dark clusters in contrast to the lighter concentrations associated with the less magnetic parent sheet. In this way, black spots are seen against the white background of the detector cell. In the "white spot" technique (see Figs. 2 and 6) the flux is made to flow diametrically across the spot, parallel to the sheet and the bottom of the detector cell. The magnetic particles then tend to accumulate at the entry and exit arcs of the spot circles leaving a lighter space between the dark "brackets" so formed. Though either method can be used, the "black spot" is to be preferred since there is then no likelihood of a bursting bubble in the detector cell being mistaken for a white spot (as may occur when using the "white spot" technique).

The method of ensuring the soundness of spot-welds as outlined above is quick, simple and reliable, and dexterity is soon acquired. It is not necessary for the magnetisation to be close to the material; provided it is of sufficient power, it can be an inch or two away. The tests are best made with the detector in a horizontal position so that gravity helps to settle the particles, giving the greatest sensitivity. Structures should be examined in their simplest state to avoid manœuvring the magnetic detector in confined spaces. Faulty spots can be marked, rewelded and then retested. Most ferrous stainless alloys can be tested by this method, but if in doubt, a few trial spot-welds should be made with the material.

Suitable captive fluid detectors and magnets as illustrated in Fig. 1 can be obtained from the New Products Sales Department of the Metropolitan-Vickers Electrical Co. Ltd., Trafford Park, Manchester, 17.

Inadequate Gasworks Plant

In most gas undertakings the coal shortage difficulties are increased by reason of gasworks plant not being adequate to meet the demand. The wear and tear on gas making plant, which operates 24 hours a day throughout the year, is heavy at any time, but plant is now being grossly overworked. Not only has it been impossible, owing to shortages of labour and materials, to complete much needed extensions, but during the last seven years it has been impracticable fully to maintain and repair plant and so keep it in good condition. Such difficulties are particularly acute in undertakings which experienced extensive war damage.

The gas industry is using every effort to overcome these difficulties, realising that any failure in the supply of gas to its domestic, industrial and commercial consumers can have a serious effect upon the life of the community, as was realised following air raid damage during the war, when the industry was able, paradoxically enough, to meet the enormous demands made upon it.

Modern Methods of Gas Analysis

Part VI.—The Haldane Apparatus

By W. D. Vint

The Haldane apparatus for the analysis of gaseous mixtures is described ; the preparation of the apparatus for use is also described and a convenient method given for the transference of the sample to the gas burette. Procedure of the analysis is given using a typical example.

THE Haldane apparatus was designed for exact air or mine gas analysis but with the incorporation of certain modifications, there is practically no limit to the range of gaseous mixtures which can be accurately analysed on this instrument.

The apparatus consists essentially of the following items :—

(1) Water jacketed graduated gas burette ;

(2) Control or compensating tube of the same capacity as the burette ;

(3) Absorption vessels for KOH and alkaline pyrogallol solutions ;

(4) Combustion vessel ;

(5) Source of electric current, either accumulator or step down mains transformer.

Description of the Apparatus

The sample of gas is measured in the gas burette A which is about 32 inches long and provided with a three-way tap. The capacity of the wider portion is about 15 cc. and is graduated at one point only, viz., the 5 cc. mark. The narrow portion of the burette has a total capacity of about 6 cc. and is graduated all the way down in divisions of 0·01 cc. With such a burette it is possible to read with the aid of a magnifying glass to within an error of 0·001 cc. and this therefore, produces in the actual sample of gas a possible accuracy to within 0·005%.

A levelling vessel B is attached by thick red rubber tubing to the bottom of the burette and clean purified mercury is used as the sealing liquid. A few drops of acidulated water are added to the surface of the mercury in the burette to ensure that a constant vapour pressure is maintained during an analysis. The gas sample itself is added at the three-way cock C and gas volumes are measured by raising or lowering the reservoir B by means of the pinion and ratchet attachment.

One side of the three-way cock is connected to the absorption vessels D and E which are about 10 cms. long by about 3cms. diameter. The vessels are of the glass tube pattern and contain respectively caustic potash and alklaline pyrogallol solutions for absorption of carbon dioxide and oxygen. The potash pipette is connected to a movable reservoir R by means of black rubber tubing, the whole being filled with 20% KOH solution. The alkaline pyrogallate solution in E is made up by adding 10 grams of pyrogallic acid dissolved in a little water to 100 cc. of nearly saturated KOH solution (S.G. 1·55 approx.). When the pyrogallic acid is dissolved, the solution is introduced into E through the tube F by means of a funnel or large pipette, the open end F being afterwards securely closed with a piece of glass rod pushed well in. G and H are partly filled with 10% KOH solution which protects the pyrogallate solution from the air and also prevents the solution becoming gradually diluted with water as happens when water is placed in G and H.

When the pyrogallate is made up, it should be allowed to stand for at least 24 hours before charging the pipettes. Should the solution be required in a short time, it can be prepared, boiled for one hour and charged into the pipette and accurate results obtained. If the solution is effectively sealed from the action of the atmosphere, it will last indefinitely and should, even in use, last about 100 absorptions. When absorption of oxygen becomes sluggish, the solution should be changed immediately.

The pressure in the burette is adjusted by using the potash pipette as a pressure gauge and bringing the potash before every reading on the burette to the mark K. The KOH solution has only one-tenth the specific gravity of the mercury and with the fine bore of the burette the level can be adjusted very accurately. To ensure that the readings of the burette are entirely independent of changes in temperature and barometric pressure during an analysis, a control or compensating tube J which stands beside the burette is utilised. The connecting tubes from J are of the same diameter and about the same length as those from the gas burette. The three-way tap at L makes it possible to equalise the pressure in J with that of the atmosphere. By using the "T" tube M, the potash solution is brought into connection with J. At the commencement of an analysis the potash is adjusted to the mark K by manipulating the potash reservoir R, L being open to the air. L is then turned so that the control tube is connected with the potash tube only and is not again turned until the analysis is complete. As each measurement is made on the burette, the potash is brought to the mark K by raising or lowering R. The potash in the absorption vessel is then brought to the corresponding mark K by adjusting the levelling tube. In this way, the burette readings are thus compensated for changes in temperature and barometric pressure. It is important that the lower end of the compensating tube is kept full of water

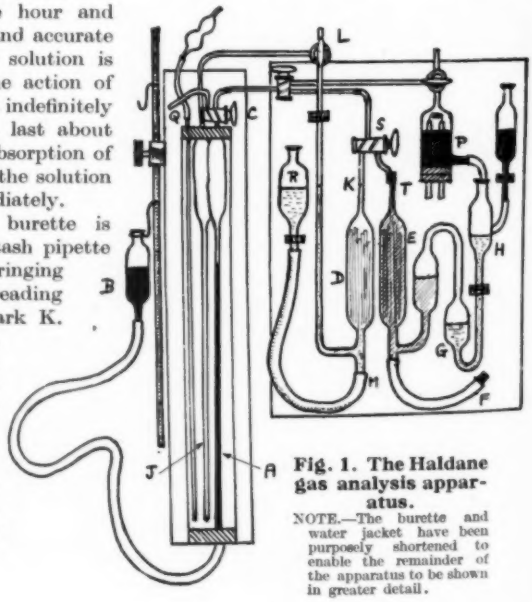


Fig. 1. The Haldane gas analysis apparatus.

NOTE.—The burette and water jacket have been purposely shortened to enable the remainder of the apparatus to be shown in greater detail.

and that the burette is kept moistened by a few drops of water acidulated with sulphuric acid.

The combustion pipette P contains a fine platinum spiral (40 gauge) supported by two glass tubes which travel through a rubber stopper at the bottom. Pieces of fairly thick platinum wire are fused in to the tops of these glass tubes and are connected inside the pipette to the spiral and with twin copper wires outside, which supply an electric current. The latter may be taken from a six volt accumulator, dry cells, or a step-down mains transformer. A switch and 10 ohms variable resistance must be included in the circuit to allow the spiral to be gradually turned to a bright white heat. It is possible with this type of heated spiral to burn completely even traces of combustible gases without the addition of pure hydrogen or methane.

Preparation of the Apparatus for Use

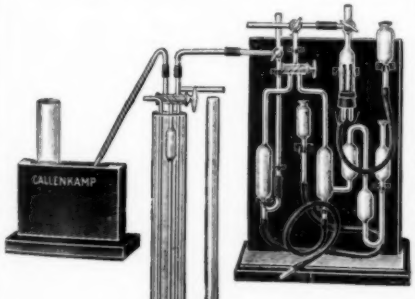
Assuming that the apparatus is replete with the necessary reagents and confining liquid, the first step is to sweep all the capillaries free from oxygen. The gas burette must contain about 20 cc. of gas (nitrogen plus any oxygen which may be present) which is then bereft of most of its oxygen by passing repeatedly into the alklaline pyrogallol solution. When the difference in volume between absorptions becomes as low as about 0·01, the nitrogen is then passed into the caustic potash, drawn back into the burette and then into the alkaline pyrogallol several times. Absorption should be continued until no difference is observed between successive readings. The potash bulb must now be swept again in a similar manner and absorption continued in the pyrogallol until no difference in readings is observed. Similarly, the combustion vessel is swept free from oxygen.

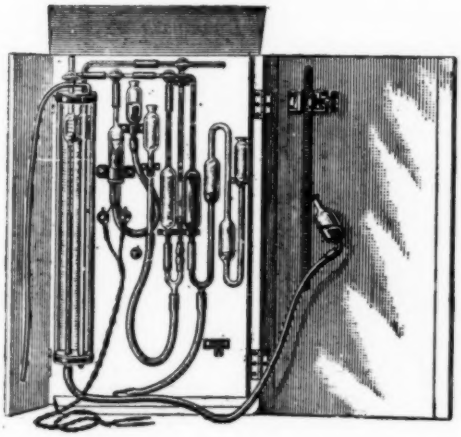
There must be no other contaminating gas present in the capillaries; if for instance, traces of hydrogen or methane had been left from a previous analysis these gases must be eliminated by either burning with air and the products of combustion absorbed in KOH or the whole apparatus swept through with air and the oxygen thus added absorbed in pyrogallol.

The position of the apparatus in the laboratory is very important. If it should be placed near a window, it is preferable that the window is one facing the north. No sunlight should be allowed to impinge directly upon the apparatus otherwise trouble will be experienced with air in the compensator tube expanding rapidly and throwing the level off the scale.

Transference of Sample to Gas Burette

The most convenient method is by utilising the type of gas sampling tube fitted with glass taps as described in a previous article of this series and connecting one end with thick rubber tubing to the point Q on the apparatus. Suspend a small test tube from the tap to catch excess mercury coming through the side limb. Turn the tap so that the burette is connected to the short side limb and raise reservoir. As soon as the air in the capillary has been replaced by mercury and the first drop spills over into the test tube turn the tap through an angle of 90 degrees. Gas and mercury are now isolated. Lower the reservoir slightly till the level is slightly below the top of the burette and turn the tap to connect with the gas in the sampling tube. The gas can now be drawn into the burette by gently lowering the reservoir. When the level in the burette has gone well below the 21·0 cc. mark close the tap C and bring the reservoir to a position such that the mercury level in the reservoir is as near the 20·0 cc. mark as possible. The level in the burette should now be somewhere below the 20·0 cc. mark and the tap C must now be very cautiously opened to let out the slight excess of unwanted gas. Stop the escape of gas when the levels are fairly near but before the level in the burette is abreast of that of the reservoir. Close the tap C, adjust the reservoir on the ratchet until the mercury in both limbs is on an equal level and turn the tap C so that it is connected to the potash pipette. The level in the latter will probably rise or fall slightly of the mark K and the reservoir must then be adjusted until the potash is exactly on the mark. The tap L of the compensator tube must now be closed.





Examples of the Haldane apparatus by A. Gallenkamp & Co. Ltd,

Procedure for Analysis

The procedure for the analysis of a gas depends upon its composition and as this is usually known approximately, a method may be selected beforehand. Take for example, the simple case of a gas consisting solely of CO_2, O_2 and N_2. The sample is transferred to the gas burette as explained previously and levels in compensating tube and potash pipette adjusted to their correct marks. Air must now be blown through the water jacket to maintain an even temperature and if the levels alter they are adjusted to the mark again. Now make connection to the pyrogallol pipette, the level of which should also be on the correct mark T. Adjust pyro' by moving the reservoir until the pyro' is on the mark. Now connect sample with the potash again. If the levels in the compensator tube and potash have altered, adjust by means of potash and mercury reservoirs at the same time blowing a good stream of air through the water jacket.

The first reading on the gas burette, with the aid of a magnifying lens can

now be taken. Now raise the mercury reservoir and force the gas into the potash pipette; lower reservoir and repeat two or three times. Gently lower reservoir and attach to the ratchet at a convenient point when the potash level in the pipette is near the mark. Force air through the jacket and adjust potash levels to the mark in both compensator and potash pipette by raising or lowering their respective reservoirs. The second reading on the burette may now be taken.

The whole process of absorption must now be repeated until successive readings are found to be constant. When this constant reading is ascertained it is noted down and the others discarded. The gas must now be passed several times into the alkaline pyrogallol solution. After about ten absorptions the mercury reservoir is placed on the hook of the ratchet, the latter of which has been adjusted until the level of pyro is as near the mark as possible. Adjust the reservoir at the same time pumping air through the water jacket until the level of pyro' is on the mark. Take the reading on the burette (it is not necessary to book the reading). Now pass the gas several times into the pyro' and take a further reading. If the difference is 0·01 or less pass the gas into the potash pipette once and then back into the pyro' several times. Now lower the mercury reservoir until the pyro' is nearly on the mark and attach to the hook of the ratchet. Adjust the ratchet until the pyro' is dead on the mark, reverse tap S thus connecting the gas sample to the KOH. Pump air through the water jacket and adjust mercury and KOH reservoirs until both KOH solutions are at the correct levels in the KOH pipette and compensator tube.

The reading on the burette can now be taken. The KOH pipette must now be swept again and absorption made in the pyrogallol and a further reading made on the burette. The process is now repeated until successive constant readings are obtained, indicating that all oxygen contained in the sample and in the KOH capillaries has been removed.

Carbon dioxide and oxygen have now been removed from the gas sample leaving only nitrogen which can be calculated by difference from 100. Suppose the three readings which have been obtained are as follows:—

20·126 .. .. Initial reading on burette.
19·258 .. .. After CO_2 absorption.
16·530 .. .. After O_2 absorption.

$$CO_2 \text{ is } \frac{20{\cdot}126 - 19{\cdot}258}{20{\cdot}126} \times 100 = 4{\cdot}31\%$$

$$O_2 \text{ is } \frac{19{\cdot}258 - 16{\cdot}530}{20{\cdot}126} \times 100 = 13{\cdot}56\%$$

N_2 is .. .. 82·13%

100·00%

In the foregoing statement, no account is taken of the errors in the burette which are nearly always present to an appreciable extent. The method by which these errors can be compensated will be described in the succeeding article.

Electrode Selection for Hard Facing

Hard facing of new and worn parts is proving an easy and inexpensive means of keeping plant and machines in better serviceable condition than the normal base metal will permit. To make effective use of this process, care must be exercised in the choice of electrodes used. In a recently published booklet much information is given on this aspect of the process and on the part played by the parent metal, extracts from which are given in this article.*

THE main purpose of depositing hard surfaces on metal parts is to improve resistance to wear and abrasion and in certain cases to provide cutting edges. The process is especially applicable to machine components subjected to heavier service than the remainder of the machine; by prolonging the life of the particular part the machine can remain in operation for a longer period, with a substantial reduction in maintenance and idle time costs. In addition to lower service costs, hard facing increases the life of a particular part, has a lower co-efficient of friction, is resistant to corrosion and can be applied successfully to cheaper base metals. Hard-faced parts will outwear the normal base materials used from 2 to 25 times, depending upon the type of hard-facing alloy used and the service to which the part is subjected.

The range of composition available is wide and varies between the special types used in cases such as worn rail ends, where a resistance to wear superior to that of the rail metal must be combined with a reasonable measure of toughness to resist impact stresses, and those compositions suitable for making synthetic lathe and other tools capable of substituting for high-speed steel and similar applications.

For convenience electrodes can be classified into three main groups, i.e., austenitic, martensitic and carbide.

Austenitic Group

The characteristic properties of the weld metal of the austenitic group are non-magnetic, low yield point, moderately low hardness (200–250 Brinell), associated with a high capacity for work hardening, due to the ready breakdown of the austenite to a type of martensite. Deformation of the surface layer of a weld occurring in service immediately produces a very hard skin with a high resistance to abrasion, while the remainder of the deposit remains relatively soft and tough. A useful combination of hardness, toughness and resistance to impact, is thus available with the austenitic alloys, without the need of thermal hardening treatment, to which they are not susceptible.

Martensitic Group

Electrodes in this group give deposits of high inherent hardness due to the presence of martensite in the micro-structure and the hardness is not greatly affected by cold work. The welds are susceptible to softening and hardening by heat treatment, consequently the hardness of a deposit will depend to some extent on the rate of cooling after welding, i.e., on the mass of plate, size of electrode and current density.

Carbide Group

Electrodes in this group consist of special steel tubes filled with fused tungsten carbide particles of definite

size grades. The oxy-acetylene process is commonly used for depositing these types, although the carbon arc and metallic arc processes can also be used. With the higher temperature of the arc, much of the carbide is dissolved in the steel to form a more or less homogeneous hard facing similar to those in the martensitic group. This type of rod deposited by the oxy-acetylene process, however, gives rise to a "sandpaper" type of layer in which hard carbide particles are embedded in the steel matrix to form an ideal cutting medium for rock and petroleum drills.

Hardness

The hardness of hard facing deposits is not constant for all applications, but varies within limits depending on the rate of cooling and the amount of dilution with basis metal. The rate of cooling is largely affected by the size of the electrode, current used, and size and shape of parts being welded. The cooling of a weld on a thin edge of metal will be much slower than a similar weld in the centre of a die block.

The composition of the first layer of weld is to a large extent determined by the interfusion with the basis metal. When deposited on mild steel the alloy content of the weld is reduced, consequently the hardness is lowered. On the other hand, when dealing with high carbon steels and certain alloy steels, the first layer will register a higher hardness than will subsequent layers.

Machining

In general, deposits giving a Brinell hardness below 300 can be machined with the usual tools. Deposits exceeding this Brinell figure require special tools, or, in some cases have to be ground to give the required finish. In special cases it may be desirable to soften by heat treatment and to reharden after machining.

Heat-treatment

In the case of the martensitic alloys the rate of cooling of the weld is usually high enough to produce adequate hardness without subsequent heat treatment. "Hardex" weld metal is exceptional in this respect, since it is susceptible to temper hardening as already mentioned. The other deposits can be softened by annealing at 700° C. and can be re-hardened by air cooling from 850°–900° C., although precautions must be taken to avoid decarburisation of the surface layers. Quenching from higher temperatures frequently produces greater hardness.

Mass of Deposit—The Buffer Layer

As a general rule it is advisable to avoid thick deposits of hard facing alloys. Since they are unable to accommodate the considerable shrinkage stresses set up and spalling of the deposit is liable to occur.

When a thick layer has to be built up and in cases where service conditions impose impact loading on the part under repair, it is often advisable to introduce a buffer layer between the hard facing and the basis metal. The depth of this layer will often be considerable and may amount to five or more layers of runs. The electrode chosen for this buffer layer should be one which will give a hardness value somewhere between that of the base metal and that of the final deposit or provide a good junction.

Basis Metal

This may be classified into two groups according to thermal hardenability :—

Low Hardenability.—The physical properties of metals in this group are not greatly affected by the localised application of heat followed by rapid cooling, and no special precautions are necessary during welding. Typical examples are carbon steels containing a maximum of 0·3% carbon, austenitic stainless steels and copper alloys.

High Hardenability.—Some metals are initially hard and brittle and readily crack due to thermal shock. This group includes high tensile alloy steels, high carbon and tool steels, high-speed steels and cast irons. As a result of the application of welding heat and the subsequent rapid cooling a zone adjacent to the weld becomes hardened and unable to accommodate shrinkage strains under restraint with the result that cracks occur in the base metal.

Precautions in Technique

To avoid hard zone cracking in the basis metal, it is necessary to preheat the article to 150°–250° C. to retard the rate of cooling. To avoid cracking in hard alloys such as high-speed steel tools, softening at 800° C. is helpful, other metals such as cast iron are not readily softened and cracking can largely be prevented by carefully preheating to 400°–600° C. followed by slow uniform cooling after welding.

When building up large areas it is advisable to divide the work into small sections and to weld in alternative positions so that heat concentrations and heat contraction stresses are not cumulative.

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* "Hard Facing with Murex Electrodes," published by Murex Welding Processes Ltd., Waltham Cross, Herts., from whom copies may be obtained free of charge.

THE August figures for iron and steel production show a substantial increase over those for July and also the production in August last year. Pig iron production was at the rate of 7,660,000 tons a year compared with 7,460,000 tons in July and 7,558,000 tons a year ago. Steel output was at the rate of 12,178,000 tons, compared with 11,007,000 tons a year in July and 11,747,000 tons in August last year.

Output of steel in the early part of the month was affected by holidays, but it rose during each week of the month and in the last week it exceeded the rate of 13½ million tons a year. Whether this rate can be maintained depends upon adequate coke supplies to enable pig iron production to be expanded to the level needed.

AN example of the value of the speed of air transport was given last month when the United Africa Co., of London, received a cable from their Timber Saw Mills at Sapele, Nigeria, requesting replacement of a heavy machine shaft. The mill, which exports large quantities of plywood and other woods to the U.K. for the housing programme, was at a standstill until another shaft was available. BOAC were asked if the requirement could be sent by air freight. Measuring 18 ft. 9 in. in length, 4 in. in dia., and weighing 320 kilos., the urgently needed steel shaft just fitted into the freight pannier of a BOAC Halton aircraft—with about 1 in. to spare. It was delivered to Nigeria within one week of receipt of the original cable requesting the replacement.

Gas-Turbine Propulsion in a Naval Vessel

Trials are in progress with a motor-gun boat, partially powered by a gas-turbine, in which the power from the jet is converted into a rotary motion to drive a shaft and propeller of a conventional kind. Some technical details are given of the compressor, combustion chamber and the power turbine.

LEADING engineering nations have been interested for a number of years in the development and marine application of the gas turbine, an engine using oil fuel but in which the motion is entirely rotary. This obviates the vibration and certain other inherent disadvantages of the " push-pull " motion of the conventional reciprocating internal combustion engine. Such an engine would combine the advantages of the smooth running steam turbine with economy in weight.

The first craft to be powered by a gas turbine has been taken to sea by the Royal Navy and the preliminary trials are proceeding satisfactorily. It is H.M. Motor Gun Boat 2009, a 110-ft. triple screw craft built by Messrs. Camper Nicholson, of Southampton. The gas turbine under trial on this craft has been developed for the Admiralty by the Metropolitan Vickers Electrical Co., Ltd. It drives the central shaft and takes the place of one of the 1,250 B.H.P. petrol engines which formerly powered her. Normal cruising and astern power is provided by two 1,250 B.H.P., 2,400 r.p.m. Packard internal combustion reciprocating engines, each engine driving its own propeller through a reduction gear. Maximum power ahead is obtained by bringing into operation the independent gas turbine of 2,500 S.H.P., which drives the third propeller through speed-reduction gear. Thus it will be noted that the craft is not jet propelled but that the power from the jet is converted into rotary motion to drive a shaft and propeller of a conventional kind.

The characteristics of the simple cycle gas turbine include low overall specific weight and size with rapid starting, and these qualities make it very suitable for light vessels where high speeds may be required for limited periods and at short notice. For experimental purposes it was decided that a jet engine that had already been developed by the Company should be employed for the gas generator portion of the plant. New development, as far as the gas turbine was concerned, was thus in the main confined to the power turbine and its gears and to certain modifications to the control system. It was fully appreciated at the outset that this jet engine or gas generator possessed performance characteristics that were not ideal for use with power turbines for duty of this character, chiefly in respect of its somewhat low compression ratio, and it was realised that overall efficiency would be affected on this account. It was felt, however, that only by such means could experience be obtained in the actual operation and control of such a craft within a reasonably short time. Moreover, with a gas turbine, that is essentially a peak load plant, fuel consumption is of secondary importance.

The Metropolitan-Vickers gas turbine plant comprises a gas generator consisting of a compressor, a combustion chamber, and a turbine driving the compressor, this being followed by a power turbine mechanically independent of the compressor turbine and coupled by a reduction gear to the propeller shaft.

Gas Generator

The compressor is a nine-stage axial flow machine with aerofoil section blades of aluminium alloy. The moving blades are mounted in axial serrated slots in a forged aluminium alloy drum, and the fixed blades in dovetail slots axially disposed in the stator casing, which is also of aluminium alloy.

The rotor is provided with a conical extension piece to the end of which is secured an extension for the mounting of the turbine disc. This combined rotor is carried in two ball bearings with the turbine disc overhung. The forward or compressor end bearing acts as a thrust bearing : the turbine end bearing is carried in a splined housing, which has freedom of axial movement against spring compression.

On the casing of the compressor are mounted various auxiliaries including fuel pump, governor, tachometer generator, electric starting motor, and lubricating oil pump, together with fuel control and relief valves. A mechanical drive for the auxiliaries is taken from the forward end of the compressor shaft through bevel gear boxes and a vertical shaft.

The combustion chamber is of the annular type developed by Metropolitan-Vickers for jet-propulsion engines, and is characterised by " straight-through " flow. The chamber consists of two concentric walls containing an annulus, within which is mounted an annular primary chamber consisting of inner and outer walls. Air entering the chamber from the compressor is divided ; the smaller portion enters the primary chamber or zone of primary combustion through a series of holes on the upstream end of this chamber, and the larger part passes to the inner and outer annuli formed between the primary chamber and the containing walls. Pool gas oil is injected in a finely atomised stream into the primary chamber through 20 fixed orifice jets in an upstream direction. The high-temperature products of combustion in the primary chamber are then mixed with the remainder of the air, which enters the chamber through a number of slots in the inner and outer walls of the primary chamber, resulting in a mixture at a temperature suitable for the turbine inlet. The sheet metal portion of the combustion chamber is of " Immaculate 5 " stainless steel which has excellent heat-resisting qualities and a coefficient of expansion approximating to that of aluminium alloy.

The turbine driving the compressor is of the two-stage type with a disc of molybdenum-vanadium steel carrying moving blading of " Nimonic 80 " alloy. A stub shaft is forged integral with the disc and is splined and locked into the end piece of the conical extension of the compressor drum. Each side of the turbine disc is cooled

by a flow of air from the centre radially outwards, the air being taken from the compressor outlet.

Power Turbine

The power turbine rotates independently of the compressor turbine. It has four stages with both fixed and moving blading of molybdenum-vanadium steel. The moving blades are mounted in axial serrations formed in a drum, also of molybdenum-vanadium steel, and the fixed blades are dovetailed into circumferential slots machined in the stator casing which is made of forged mild steel.

The drum is supported from the central shaft by two dished end pieces; that at the after end is secured rigidly to the shaft, and that at the forward end is connected to the shaft through the medium of discs, which are flexible in an axial direction in order to deal with differential axial expansion of the drum and shaft. The shaft itself is carried in two ball bearings; the forward bearing is mounted in a spring-loaded housing which floats axially to deal with expansion; this housing is carried by a fabricated steel inlet branch through a number of struts of aerofoil section. The after bearing is similarly supported. The after bearing is designed to take the axial thrust on the blading and is mounted in a spherical seating permitting slight angular movement. The interior of the drum is cooled by a flow of air led through external pipes from the fifth stage of the compressor. The gas generator outer casing is connected to that of the turbine by means of a bellows type expansion piece. The hot gases on leaving the power turbine are passed through an outlet volute of fabricated sheet steel; this turns the flow in a vertical direction to the exhaust.

Speed Reduction Gear

The gear is double-helical single-reduction. The drive from the power turbine is taken through a flexible quill shaft, which passes through a hollow pinion, to which it is attached at the end remote from the turbine. The pinion is carried in roller bearings without axial location. It was necessary to provide means to permit the gas turbine propeller to rotate idly when the reciprocating engines alone were in service and thus avoid motoring the power turbine rotor with consequent blade windage losses. To fulfil this purpose the gear incorporates a Sinclair self-synchronising clutch mechanism developed by the Hydraulic Coupling & Engineering Co., Ltd.

The low-speed gear wheel is in two halves with one helix formed on each, and both portions are free to slide axially on the shaft. The principle of operation of this mechanism is that loads on the driving teeth cause the two single helical wheels to be drawn together and held in that position; the main drive is then transmitted from the wheels to the shaft through the engagement of two sets of internally and externally toothed rings mounted on the wheels and shaft, respectively. When the driving power is cut off and the propeller shaft continues to be rotated by the trailing of the propeller, the helices cause the wheels to slide apart and the toothed rings disengage. In this disengaged position the teeth of the internally toothed rings mounted on the gear wheel pass over a series of spring-loaded pawls, which provide the initial resistance that, when power is restored, causes the wheels to be brought back into full engagement with the shaft.

When the vessel is cruising, the trailing of the gas turbine propeller rotates the oil pump at a speed sufficient to maintain an oil pressure in excess of the tripping pressure, so permitting the starting up of the gas plant. Under test bed or dock trial conditions, however, the propeller would be at rest, and a hand pump is provided to enable sufficient oil pressure to be established to allow the starting of the plant.

As the gas plant is out of service for long cruising periods, the ball and roller bearings of the plant might, if the rotors remained stationary, suffer damage due to the vibration of the internal combustion engines. With the gas turbine propeller trailing, the oil drag between the gear slow-speed shaft and the gear-wheel bushes is sufficient to cause slow rotation of the gear wheels, pinion and power turbine rotor, but as the gas generator rotor has no mechanical connection with the propeller shaft a separate inching motor is provided for this element. This motor is of 1/16 h.p. and drives through a double worm reduction gear.

Control System

The control of the power output is effected solely by regulation of the fuel quantity admitted to the combustion chamber of the gas generator. This fuel quantity and the prevailing atmospheric conditions dictate the speed at which the gas generator will run and so determine the gas flow rate and the temperature and pressure at the inlet to the power turbine; these in turn determine the power output.

The gas generator portion of gas turbine plant has a minimum running speed, known as the idling speed, from which or from any higher speed it is possible to make rapid acceleration to full speed. On starting up external means are required to bring the speed up to the self-sustaining speed (which is less than the idling speed), but beyond it control is effected solely by the regulation of fuel admission.

To bring the gas plant into operation, the rotor of the gas generator is run up by means of a 24-volt D.C. electric starting motor to about 800–1,000 r.p.m., so establishing conditions for the satisfactory lighting up of the combustion chamber. The ignition is effected electrically. A solenoid valve when energised permits fuel to pass from the main fuel pump delivery to igniter jets formed with each of two ignition plugs, spark ignition taking place through the medium of a boost coil. When ignition has taken place some power assistance is received from the turbine, but at this low speed it is insufficient alone to drive the compressor. It is, therefore, necessary to continue the motor drive until a speed of about 2,000 r.p.m. is reached, when the machine becomes self-sustaining. The motor is then switched off, and the unit accelerates to the idling speed under the control of an automatic starting valve. This starting valve is servo-operated and is designed to ensure that the fuel flow into the combustion chamber gradually increases in step with the pressure build-up, so that the gas generator accelerates at a safe rate.

The main throttle or control valve consists essentially of a tapered needle moving in an orifice, the movement of the needle being servo-operated and automatically controlled to give a rate of acceleration that is as high as possible consistent with freedom from risk of stalling of the compressor. This valve is actuated from the control desk by a rack-and-pinion mechanism.

The maximum operating speed of the gas generator is controlled by an overspeed governor, which prevents

the speed from exceeding the selected maximum value by the automatic throttling of the fuel admission to the combustion chamber.

The operating speed of the power turbine, which is mechanically separate from the compressor turbine, is normally dictated by the relation between power input from the gas generator and power absorption by the propeller, but an emergency trip governor of the bolt type is provided; when the speed exceeds the designed maximum operating speed by 11%, this acts on the fuel supply to the gas generator to shut down the entire gas unit.

The time for starting up the gas generator from cold and running up to the idling speed of 3,000 r.p.m. is of the order of 45 seconds.

Larger Gas Turbine Machinery Planned

It should be kept in mind that this M.G.B. 2009 installation is essentially an experimental one, designed to give practical experience in this new field of marine propulsion. It will not create speed records. The gas turbine power unit does, however, produce a remarkable power for the space and weight devoted to it, and it augurs well for the future of gas turbine propulsion. It may well bring about a revolution in the performance of the smaller fighting ships. It is noteworthy that the Admiralty is already planning larger gas turbine machinery for installation in a vessel of the escort type. This further project has been designed as a marine propulsion unit from the start, and it is predicted that its durability and efficiency will be greater than those of the engine now under trial.

Damping Capacity, Strain Hardening and Fatigue

Fatigue Failure of Certain Alloys is Preceded by Strain Hardening

WHEN a polycrystalline metal is subjected to alternating stresses, the material may fail by fracture after a certain number of stress cycles even though the maximum stress involved is considerably lower than the static stress required to cause rupture. Described in general terms as fatigue, this phenomenon is investigated conventionally by subjecting a specimen of the metal to an alternating stress (frequency normally about 100 cycles per second), the number of stress cycles required to cause fracture being recorded. A series of tests of this type, over a range of maximum values of the alternating stress, gives a fatigue curve for the material.

Strain hardening is a result of plastic or irreversible straining of the metal and is characterised by an increase in the stress necessary to produce a defined amount of plastic strain—i.e., as an increase in the limit of proportionality or proof stress. During strain hardening a part of the work done is stored in the metal and subsequently may be released by annealing.

Damping capacity, or internal friction, refers to the capacity of a solid to convert vibrational energy to some other form. It is defined normally as Δ/E where ΔE is the energy absorbed and/or dissipated during each cycle of the vibration, and E is the total mechanical energy stored within the material for defined conditions of vibration.

Fatigue and strain hardening are the results of energy conversion, whilst damping capacity expresses the ability of the material to cause this conversion. A recent paper by Hanstock* on the subject has for its object an examination of the relationship of damping capacity to strain hardening and fatigue by referring to an experimental examination of two alloys of aluminium and magnesium.

The work became possible as a result of the development of a method of measuring damping capacity during vibration tests on specimens at strains within the fatigue range. This method is described in an earlier paper† which also records that damping capacity is a function of the maximum vibrational surface strain, ϕ, of the metallurgical state and of the vibrational history of the specimen. It is also known, qualitatively, that $\Delta E/E$ is sensitively dependent on the temperature of the specimen when a certain temperature, probably characteristic of the material, is exceeded. In the present investigation, the temperature of the specimens was kept within the region where $\Delta E/E$ is insensitive to variations of temperature.

As a result of this work it is shown that fatigue failure of aluminium alloys containing 5% and 11% of magnesium is preceded by strain hardening. Strain hardening commences when the shear strain exceeds the primary limit of proportionality of the alloy. Below this strain the damping capacity, which is small (3×10^{-5}) and substantially constant, is not associated with plastic strain as normally understood, but, above this strain, work done in causing plastic strain provides an increasingly large contribution to the damping capacity.

For strains exceeding the primary limit of proportionality, the damping capacity is a function of time of vibration, decreasing as the metal strain hardens to an amount ultimately equivalent to an increase of the limit of proportionality by about 120% for the 5% alloy and about 65% for the 11% alloy. The results suggest that fatigue failures occur when the total amount of irreversible strain caused by vibration reaches a certain value characteristic of the alloy, endurance being dependent on the amount of irreversible strain per cycle.

* R. F. Hanstock, *Proc. Phy. Soc.*, 1947, **59**, 275. Reprint may be obtained from High Duty Alloys, Ltd., Slough, Bucks.

† R. F. Hanstock and J. Murray, 1946, *Jour. Inst. Met.*, **72**, 97.

The Aluminium Development Association

IN an earlier issue of this journal reference was made to a brochure published by the above Association describing its aims, activities and organisation. A new publication recently issued, which will prove a useful adjunct to this brochure, gives a complete list to date of the Member Companies forming the Association, with the addresses of their main, branch and sales officers, and particulars of associated companies. The main activities of each of the Companies are briefly stated, and an index of products is also provided. This new publication corresponds in size and form to previous brochures and will be useful to readers as a directory of member firms and of their particular products. Copies are available on application to The Aluminium Development Association, 33, Grosvenor Street, London, W. 1.

The Effect of Notching on Materials of Construction under Static and Dynamic Tension

(Maximum Testing Velocity 29 feet/second)

By Dr. Georges Welter,

Professor of Applied Mechanics, Ecole Polytechnique, Montreal.

This report discusses the results of static and dynamic tests performed in order to determine the effect of notches in specimens of various construction materials. The maximum initial testing velocity used was about 29 ft. per sec.

The properties of some light alloys and other structural materials were measured by comparing impact loading with static loading force-elongation diagrams recorded on a specially designed device. A tangential dynamometer with a spiral spring adjusted between steel strips records the dynamic load while simultaneously the elongation of the specimen is recorded by the rotating movement of a drum in a perpendicular direction. The maximum dynamic load that can be recorded by this device is about 3,000 lbs.

The total energy, the elongation and the energy absorbed per unit volume, for six different materials, were measured on specimens tested at a rate of straining of 0·005 ft. per second and compared with the same values measured on identical specimens strained about 20,000 times faster. As the volume and not only the section of the specimen or the structural member absorbs the applied load, it seems that the strength calculated per unit volume is a more reliable value than the strength calculated per unit section.

These tests confirm the conclusions reached in a previous investigation, to the effect that the dynamic strength of cylindrical 2 in. gauge length specimens, at a speed of 11·78 ft. per second, is up to 60% higher than the static strength, depending on the material tested; in the case of zinc, it is 100% higher. At higher speeds, the ultimate strength is still increased. Furthermore, the notching effect under static and dynamic loads is very pronounced for all materials tested.

The dynamic as well as the static strength increases with decreasing gauge lengths, the amounts depending on the ductile properties of the material tested and the speed of the impact loads.

Notched specimens are very sensitive to impact loads at high speed, and even very ductile materials stand this test only in the annealed condition.

Most materials can be classified in three groups according to their behaviour under impact loads. The first group includes materials which are brittle at low impact speeds whether the specimen is cylindrical or notched. In the second group belong the materials whose strength and elongation increase with increasing speed when tested in the form of cylindrical specimens of at least ½ in. gauge length; however, these materials are very sensitive to the introduction of a notch in the specimens, which checks the flow of material. The third group comprises extremely tough materials (such as nickel-iron and nickel-copper alloys) which have the valuable property of flowing locally at the bottom of the notch even under high deformation speeds.

Introduction

IN the design of structures and machinery, the behaviour of the material under service conditions becomes a factor of increasing importance. To-day, the design of machines is largely based on the static properties of the material even if the elements of the machine are to be subjected to dynamic loads. Without any doubt the fundamentals about the dynamic strength of structural material are of the greatest importance for the rational design of machinery of all kinds. It is well known that the mechanical properties of metals are largely influenced by the shape of the specimen and the type of loading used in testing. Thus, we know that, on one hand, notches and other changes in the shape of the test specimen have a marked effect on its resistance and that, on the other hand, the rate of application of the load encountered in engineering practice is not without influence on the mechanical properties of metals. Comparison of force-elongation diagrams recorded under impact loading, with similar diagrams recorded under static loading conditions, provides useful information on the behaviour of materials. The tests described in the following pages were performed in order to obtain a comparison between the mechanical properties of light alloys and those of various other structural materials.

This investigation was made possible through funds from the National Research Council, Ottawa (Committee on Assisted Researches), for which the author wishes to express here his gratitude. A part of this work was presented as theses at the Ecole Polytechnique, in April, 1943, by M. N. Joubert, and in April, 1944, by A. Leclerc. The author appreciates their assistance in the performance of valuable work preliminary to this investigation.

Previous investigations along similar lines are indicated.

The dynamic tests were made with loading speeds of 11·78, 16·68 and 29 ft./sec. and the results were compared with records of the same material tested under static conditions with a speed of practically 0 ft./sec. All tests were of the tensile type and the gauge length of the specimens varied by small increases, from $\frac{1}{32}$ in. to 2 in.

Typical results of previous investigations are given in Table I and show that the resistance of most materials increases distinctly in function of the testing speed.

Apparatus

A new type of equipment for recording the force-elongation diagrams in a very short time had to be developed in order to accomplish this work. Up to date, different types of apparatus to make rapid tensile tests have been proposed for this kind of work, none however giving completely satisfactory results. In particular, the fundamental problem of securing clear and satisfactory load-deformation curves, on the records, has not yet been solved. Most of these devices, which operate either on the principle of electrical registration by means of strain gauges or piezo quartz and oscillographs, or on the principle of photographic recording, have not as yet been evolved to give quite satisfactory diagrams.[1, 2, 3, 4]

1 R. Plank. *V.D.I.*, Vol. 56, pp. 17–24, 46–51, 1927.
2 Seehase–Forschungsarbeiten. *V.D.I.*, No. 182, 1913.
3 E. Meyer–Forschungsarbeiten. *V.D.I.*, No. 295, pp.62–73, 1937.
4 N. N. Davidenkoff. *A.S.M.E.*, Vol. 56, pp.97–108, 1934.

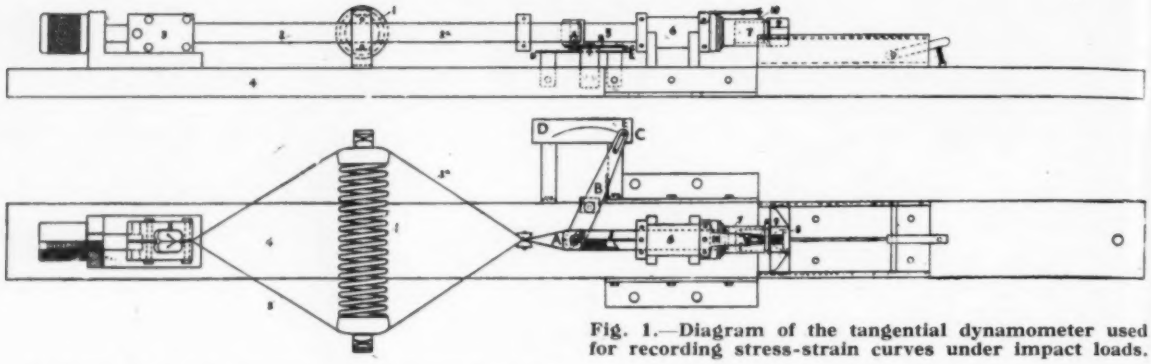


Fig. 1.—Diagram of the tangential dynamometer used for recording stress-strain curves under impact loads.

As shown in Fig. 1, the apparatus developed for the present investigation consists of a tangential dynamometer which is composed of a spiral spring (1) adjusted between two steel strips (2 and 2A) forming a lozenge fixed at one end with a special grip (3) on an iron channel (4) as a base. At the other end, the steel strip is attached on a tube (5) sliding in a central cylindrical part (6), also fixed to the iron channel (4). At the end of this tube (5) is rigidly attached one end of the test specimen adjusted in a recording drum (7); this recorder is composed of a cylindrical drum fixed on a tube fitted with helicoidal grooves (Fig. 2). As a result of the presence of these grooves, the drum turns around its axis if the specimen elongates. By means of a ball-shaped nut (8), the specimen is fixed at its other end to a guided steel cross-arm (9) upon which the impact load is applied. During the stretching phase of the specimen under dynamic loads, the elongation can be recorded on diagram paper placed on the outside of the drum (7). As, on the other hand, the dynamic load can be measured by a longitudinal displacement of the cylinder, the load is recorded on the diagram in the direction of the axis of the drum by a pencil (10) fixed rigidly on the cylindrical part (6). The elongation of the specimen is recorded by a rotating movement of the drum in a direction perpendicular to the direction of the load applied. Half an inch on the abscissa represents an elongation of the specimen of about 15%. Copies of a few original curves, one static the other dynamic, recorded with this apparatus, are reproduced in Fig. 3. The elongation measured after the test, on the specimen, and reported in abscissa on the diagram, indicates the end of the load-deformation curve. To obtain these records, the apparatus described above is placed in a static tensile machine, as

Fig. 1a.—Photograph of the dynamometer illustrated in Fig. 1.

Fig. 4.—Apparatus adjusted in static tensile testing machine.

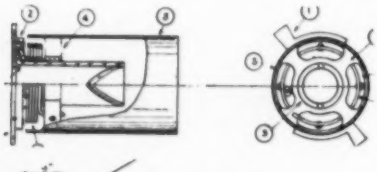
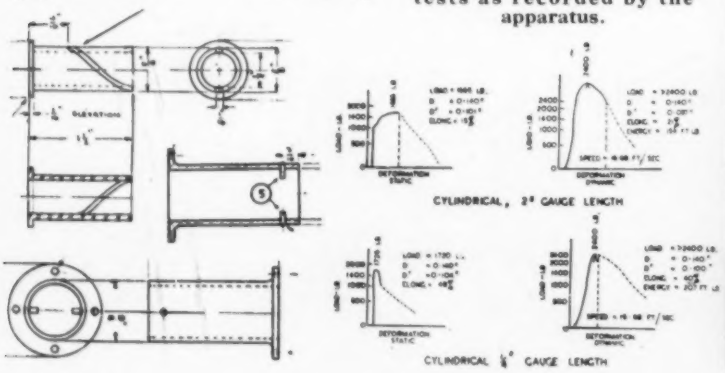
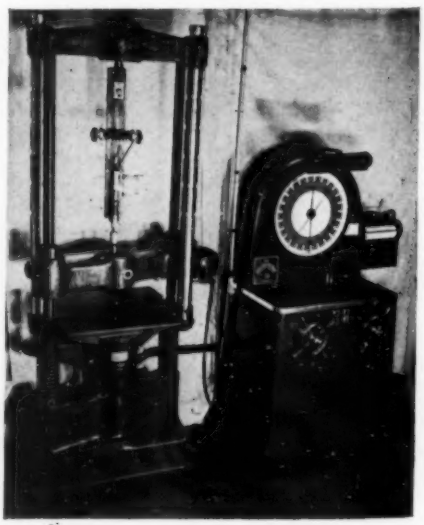


Fig. 2.—Recording drum with helicoidal grooves for strain measurement.

Fig. 3.—Copies of the original curves of static and dynamic tests as recorded by the apparatus.





shown in Fig. 4, or in a 220 ft.-lbs. impact machine of the Charpy type, as shown in Fig. 5. Two different striking velocities of about 12 and 17 ft./sec. are available with this device. This speed is the initial velocity of the specimen at the striking moment. In the early part of this investigation, this striking velocity seemed sufficient for these tests. Later on, however, a higher velocity up to about 29 ft./sec. was found necessary, thus providing one more increment in speed in order to study the behaviour of structural material under dynamic tension. As a pendulum impact machine with high striking velocity was not available, a heavy impact machine was specially designed and constructed for this purpose at the Ecole Polytechnique. This machine, with a capacity of about 350 ft./lbs. has a hammer weight at the striking edge of 46 lbs. and a pendulum length of 7 ft. It is shown in Fig. 6. The maximum load which can be applied dynamically or statically to this apparatus is through the use of an helicoidal spring of 280 lbs. per inch deformation of the order of 3,000 lbs. By using a weaker or a stronger spring, smaller or even higher loads can be applied to this device. At the beginning of this investigation, this device was used with a maximum load of about 1,500 lbs.; gradually this maximum load was increased, through the use of stronger steel strips and more resistant springs to about 3,000 lbs. The mass of the apparatus put into motion during the dynamic tension of the specimen is, compared to the maximum load, fairly low. By the displacement of a total dead weight of only 2·5 to 3 lbs. on a distance of less than 1½ in. the load-deformation curves are automatically recorded. The energy absorbed by the movable parts, compared to the maximum energy range of the apparatus is small. At a speed of 11·78 ft./sec. about 6 ft.-lbs. are necessary to put the dead load of 2·5 to 3 lbs. into motion so that specimens breaking at a lower energy cannot be tested with the necessary accuracy. By reducing the weight of the parts put into motion of about 50%, an energy of over 3 ft.-lbs. could be measured at this speed. At higher speeds the minimum energy which the specimen has to surpass is naturally greater.

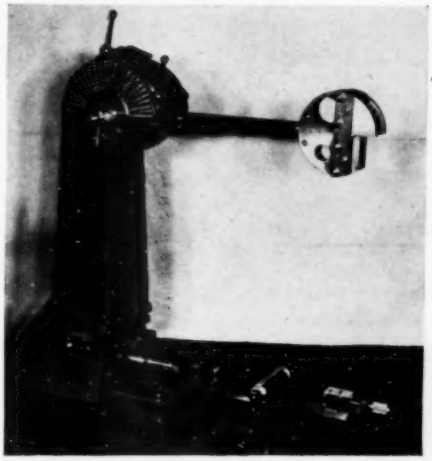


Fig. 5.—Apparatus adjusted in impact hammer (speed 11.79 and 16.68 ft./sec.)

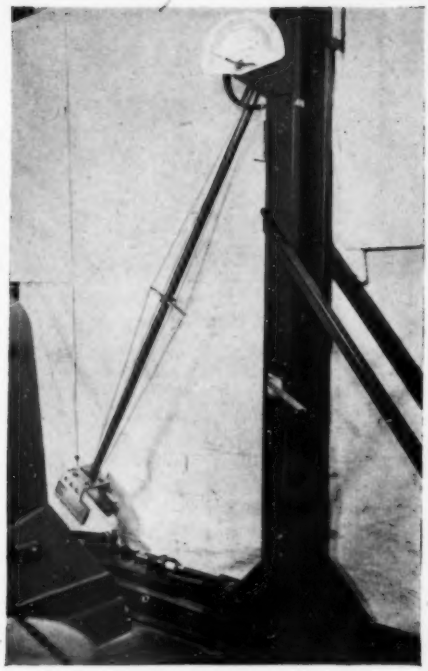


Fig. 6.—Photograph of the special high speed impact hammer (speed 29 ft./sec.)

TABLE I.
SHOWING THE RATIO OF DYNAMIC TO STATIC STRENGTH RECORDED IN PREVIOUS INVESTIGATIONS.

Material	Ratio $\frac{\text{dynamic strength}}{\text{static strength}}$	Investigator	Date	Reference No.
Steel	1·46	Plank	1912	1
	1·02	Seehase	1915	2
	1·14	Meyer	1927	3
	1·08 ÷	Windlock &	1937	9
	1·13	Leiter		
	1·22 ÷	Welter	1939	°
	1·47			
0·09% C.	1·37			
0·15% C.	1·50	Welter	1940	12
0·5% C.	1·19			
Copper	1·13	Seehase	1915	2
	1·15	Meyer	1927	3
	1·21 ÷	Honegger	1935	5
	1·27			
	1·67	Welter	1940	12
Brass	1·01	Seehase	1915	2
(58% Cu)	1·02	Meyer	1927	3
	1·35	Welter	1939	°
	1·29	Welter	1940	12
Aluminium ..	1·10 ÷	Honegger	1935	5
	1·25			
	1·30	Welter	1940	12
Duralumin ..	1·11	Welter	1939	°
17 ST	1·20	Welter	1940	12
Zinc soft	1·25	Welter	1940	12
Cast Iron	0·085	Welter	1939	°

° Unpublished.

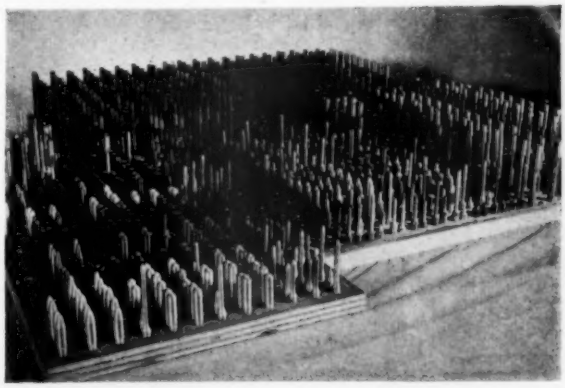


Fig. 7.—Specimens before and after the tests.

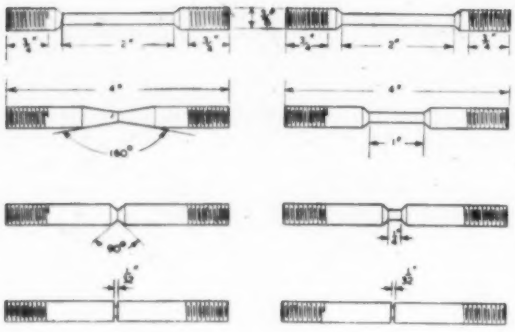


Fig. 8.—Diagram showing dimensions and shapes of specimens.

In order to check the ultimate load recorded on the drum during the dynamic test, a special device was developed to measure this load with a satisfactory accuracy. The readings of this additional device are checked simultaneously with a static calibration of the tangential dynamometer in the tensile testing machine, as shown in Fig. 4. This additional recorder indicates the ultimate load in a satisfactory manner within an error of less than 1%.

Testing Procedure

Before launching the main test programme, a preliminary study of the energy per unit volume absorbed by the test specimens of different gauge lengths was made on different materials. Besides the energy absorbed, the total elongation after the test was measured. The specimens used for this purpose had gauge lengths of $\frac{1}{32}$ in., $\frac{1}{16}$ in., $\frac{1}{8}$ in., $\frac{1}{4}$ in., $\frac{1}{2}$ in., 1 in. and 2 in. The diameter of the specimens of the different materials varied according to their ultimate strength between 0·15 in. and 0·20 in. The energy absorbed up to the point of rupture in the static test was calculated from the load-deformation diagram recorded by the testing machine, while in the dynamic test the total energy was indicated by the impact machine. For all tests the energy per unit volume was also calculated.

For the notched-bar tests under different testing velocities, specimens of 0·175 in. and 0·2 in. diameter with 1 in., $\frac{1}{4}$ in. and $\frac{1}{32}$ in. gauge lengths or with different "V" notches, were used in order that the volume of the specimen and, consequently, the total energy would vary within wide limits. Some of the specimens before and after testing are shown in Fig. 7. Including the preliminary tests, about 700 accurately machined specimens of various shapes, illustrated in Fig. 8 were used for this investigation. In most cases, two specimens for the same test were prepared and tested in order to eliminate erroneous results.

TABLE II.
MATERIALS TESTED.

No.	Material	Condition (Temper.)	Nominal Composition %	Brinell Hardness No.
1	Aluminium 2S	Drawn Annealed	Min. 99% Al	— 22
2	Aluminium Alloy	Wrought, Heat Treated Annealed	4% Cu, 0·5% Mn, 0·5% Mg, Bal. Al	110 —
3	Copper	Drawn Annealed	Min. 99·9% Cu	68·6 37·9
4	Brass	Drawn Annealed	62–63% Cu, 35% Zn, 2% Pb	— 72·0
5	Magnesium AM 57 S	Drawn	6% Al, 1% Zn, 0·2% Mn 0·3% Si, Bal. Mg	61·3
6	Zinc	Drawn	99·82% Zn	52·5
7	Monel RB	As received	67% Ni, 30% Cu, 1·4% Fe, 1% Mn	117
8	Steel mild I—Armco	As received	0·1–0·2% C, 0·3–0·6% Mn	108
9	Steel mild II—AB	As received	0·15–0·25% C, 0·3–0·6% Mn	179
10	Steel med. BC	As received	0·4–0·5% C, 0·6–1% Mn	165

Material Tested

The materials used, their designation, nominal composition and Brinell hardness are listed in Table II. Most of the materials were tested in the "as received" condition; a few of the materials however, which were delivered in a cold worked condition, were tested in both conditions; "as received" and after an "annealing and normalising heat treatment." (*To be continued.*)

Institution of Metallurgists

THE above Institution recently held a Refresher Course in the L.M.S. School of Transport in Derby. When it was organised there were some doubts of the success of such a venture, but some evidence of the progress of this new Institution is indicated by the fact that some 70 members, representing all grades of membership, lived and worked together over a week-end. The theme of the studies was "The Transformation of Solid Metals and Alloys," and seven lectures were given. Professor F. C. Thompson began the course with a general review of the subject and the further lectures were concerned with particular aspects. Professor J. H. Andrew gave a lecture on the transformation of austenite in steels; the determination of time-temperature transformation curves in steels, by Mr. E. H. Buchnall; the practical aspects of austempering and other treatment of steels, by Mr. J. Shaw; the formation of graphite in cast iron and related alloys, by Mr. J. G. Pearce; atomic changes in solid solutions including age-hardening, and order-disorder transformations in solid solutions by Dr. G. V. Raynor.

Informal discussions followed each lecture and, while the newer physical methods of approach to problems of transformation had a good deal of attention, it was apparent that there is still room for further development and greater use of the more classical methods of the older school of metallurgists in the study of this subject. It is noteworthy that all present were convinced that this type of meeting is likely, in the future, to play a most important part in the work of this Institution. Certainly the organisers are to be congratulated on the success achieved and readers contemplating associating themselves with this live Institution should contact the Secretary, 4, Grosvenor Gardens, London, S.W. 1.

The Minister of Education has recently made regulations for Technical State Scholarships under powers conferred upon him by the Education Act, 1944. Copies of these Regulations are obtainable from H.M. Stationery Office, or through booksellers, price 1d., reference S. R. & O., 1947, No. 1471.

ONE has often had held up as a dreadful warning the impetuous scientist who "rushes into print." It seems to us that this hypothetical scientist, like the chemist with acid-stained fingers, occurs more commonly in the pages of which the print are composed than in actual fact. Nowadays, indeed, he is lucky who can rush at anything greater than a snail's pace to the immortality of black ink. But when all shortages are taken into account, one instance remains with us of a reluctance to commit anything to paper which is not only inexplicable, but is also the cause of much concern to microchemists. We may be allowed to look back a little. In December, 1943, when this section first appeared, we commented on the urgent need for standardisation of certain pieces of microchemical apparatus. In March, 1944, we noted with considerable approval that the British Standards Institution had appointed two panels to prepare draft specifications for some of the more important apparatus used in combustion analysis, and for a selection of volumetric apparatus. A comment was added to the effect that American chemists had already carried out this necessary work. In January, 1946, we permitted ourselves to wonder, rather plaintively, when some of the results of this activity by the British Standards Institution would be made available to us. Now, after a further eighteen months, we feel rather more than plaintive. Such information as is available to us suggests that the fault does not lie with the panels, who have done their part of the job as far as they have been permitted—or convened. Where, then, does this delay arise ? Three years seems an unduly long time for papers to lie at the bottom of a tray on a desk. May we respectfully suggest to the B.S.I. that their next spring clean be a thorough one.

Applications of the Polarograph to Metallurgical Analysis

Part III—Further Studies on a Polarographic Method for the Determination of Lead in Copper Base Alloys

By G. W. C. Milner

Chemistry Department, University College, Hull.

A method, previously described, for the polarographic determinaion of lead in copper base alloys suffers from interference by manganese. An improved method has been devised which is suitable for alloys containing appreciable amounts of the interfering element.

IN a previous paper[1] suitable direct methods were described for the polarographic determination of lead in brasses and bronzes, using the reduction of the biplumbite ion at the dropping mercury cathode from an alkaline cyanide medium. In the case of alloys containing manganese greater than 1·0%, the addition of a small amount of ammonium citrate was recommended to retard the precipitation of manganese hydroxide sufficiently to allow the lead determination to be completed. However, this technique was soon found to be unsuitable in batch analysis, and further work was carried out in order to improve the method.

In the satisfactory method developed for alloys in which manganese is present in small amounts only, any ferric ions present are removed from the solution along with the copper ions, on the addition of potassium cyanide, which forms stable cyanide complexes with both copper and iron. Therefore, on adding sodium hydroxide to complete the base electrolyte no precipitate of ferric hydroxide is produced. However, on modifying this method to be suitable for alloys containing high percentages of manganese by adding 2 ml. of an ammonium citrate solution before the potassium cyanide, iron gave difficulty. It formed the ferric citrate complex which prevented the formation of ferrocyanide on the addition of potassium cyanide, but which caused ferric hydroxide to be precipitated on the addition of sodium hydroxide. This effect was readily overcome by adding the ammonium citrate after the potassium cyanide but before the sodium hydroxide so allowing the ferrocyanide to be formed.

1 Milner, G. W. C. *Analyst*, 1945, 70, 250–253.

A far more serious fault, however, was the gradual precipitation of the manganese hydroxide even after the addition of 2 ml. ammonium citrate. Attempts were made to prevent the precipitation completely by adding larger amounts of citrate, but the large amount necessary altered the base electrolyte so much that the definition of the lead curve deteriorated. Some success was achieved using a 1 molar sodium potassium tartrate solution instead of the ammonium citrate solution, but the polarograms obtained for lead had a steeply increasing limiting current and so the method could not be recommended. Investigations were, therefore, carried out to find another method of removing the manganese interference.

Removal of Manganese Interference

These investigations followed two lines :—

1. The complete removal of the manganese from an acid solution of the alloy prior to the polarographic determination of the lead.

2. The formation of a soluble manganese complex ion which is stable in the alkaline cyanide base electrolyte and does not reduce at the dropping mercury electrode near to the potential at which the biplumbite ions reduce.

Potassium bromate was found to precipitate the manganese completely, as manganese dioxide from a nitric acid solution of the alloy. But on testing this precipitation thoroughly in the presence of lead, it was found that a small amount of lead was always removed with the manganese dioxide. The application of this method of removing manganese from copper base alloys therefore proved unsuitable and so the second line of investigation was pursued.

Many complexing agents have been tested, but little success was achieved until the ethanolamines, orginally used in polarography by Wolfson[2] were tried. It was discovered that triethanolamine forms a very stable, highly coloured complex with manganese in the alkaline cyanide medium required for the lead determination. Using a 25% solution of triethanolamine in water in place of the ammonium citrate solution in the original method, lead was found to give reproducible and well defined polarograms having a half-wave potential of —0·4 volts with respect to the mercury pool anode. Using this modified base electrolyte, therefore, there is no necessity to use 2 volts across the main potentiometer.

The effect of the new modified base electrolyte on the other elements present in brasses and bronzes was next investigated, and it was found that ferric iron forms a triethanolamine complex which is reducible at the dropping mercury cathode. The half-wave potential of this ferric iron complex curve is —0·4 volts with respect to the mercury pool anode. This coincides with the biplumbite curve and so it is necessary to remove the ferric ions from the solution, by complex formation if possible. We have shown that this can be accomplished by the correct addition of the potassium cyanide, so that it was only necessary to alter the order in which the reagents were added to the solution of the sample. Potassium cyanide was first added to form the ferrocyanide and cuprocyanide ions, then triethanolamine to form the stable manganese complex, and lastly sodium hydroxide to form the biplumbite ion. In this way the copper and iron curves are removed from the region of the biplumbite curve and also the precipitation of manganese is completely eliminated. No other element interferes.

As a further simplification of the original method the drillings were dissolved in dilute nitric acid (sp. gr. 1·20).

Experimental Method

The following improved method is therefore recommended for the rapid determination of lead (greater than 0·1%) in any copper base alloy containing any of the usual alloying elements including manganese.

Dissolve 2·0 g. sample in 25 mls. nitric acid (sp. gr. 1·20) and boil off the nitrous fumes. Cool, and make up to 50 mls. Pour a quantity through a dry Whatman No. 40 filter paper into a dry beaker to remove the metastannic acid.

Pipette 10 mls. of the filtrate into a dry beaker and add the following solutions accurately from burettes in the order given :—

(1) 10 mls. sodium sulphite solution (50 g. in 100 mls. of water) ;

(2) 16 mls. 13% potassium cyanide solution.

Agitate the mixture continuously so that the flocculent precipitate of cuprous cyanide redissolves to form the stable cuprocyanide ion. Then add :—

(3) 5 mls. 25% solution of triethanolamine in water ;

(4) 10 mls. 10 N sodium hydroxide solution ;

(5) 2 mls. 0·2% solution of gelatine in water.

Pour a quantity of this well-mixed solution into a polarograph cell, add a pool of mercury to form the anode, and place the cell in a thermostat at 25° C. for 10 mins. Record the polarogram, using an appropriate sensitivity of the Tinsley Polarograph. Range 0 to —1·0 volts, applying 4 volts across the main potentiometer.

Results

To 2 g. portions of pure copper each dissolved in 25 mls. nitric acid (sp. gr. 1·20) a standard lead solution was added to give the following two ranges of alloys :—

(1) Lead varying from 1·0 to 5·0%.

(2) Lead varying from 0·2 to 1·0%.

(The standard lead solution was prepared by dissolving 1 g. spectrographically pure lead in a small quantity of nitric acid (sp. gr. 1·20) and making up to a litre.)

The above method was carried out on these solutions with the results shown in Table I. In each case the graph of the results is a straight line passing through the origin.

TABLE I.

% lead	Height of curve in divisions. Sensitivity in Micro amps.		% lead	Height of curve in divisions. Sensitivity in Micro amps.		
	S4	S2		S20	S10	S5
1·0	22·25	—	5·0	22·25	—	—
0·8	17·5	34·75	4·0	17·5	35·5	—
0·6	13·25	26·5	3·0	13·0	26·5	—
0·4	9·0	18·0	2·0	8·75	17·75	35·75
0·2	4·5	9·25	1·0	4·0	8·5	18·0

The above method was then carried out on many samples of brasses with the results shown in Table II.

These results, obtained by the modified method, attain the same degree of accuracy as the original method without encountering any of its difficulties. The manganese is held firmly in solution by the triethanolamine and does not begin to precipitate even after standing overnight (column 3) ; the lead polarograms are just as well defined without the use of 2 volts across the main potentiometer and excellent results

2 Wolfson, H. *Nature*, 1944, 153, 375–376.

TABLE II.

Sample No.	Elements, %											
	Cu	Sn	Ni	Fe	Al	Mn	Zn	Sb, As	Pb Chem.	Pb Polarog. 1	2	3
1	58·43	0·48	0·64	0·16	—	0·11	38·31	—	1·87	1·84	1·78	1·90
2	59·10	0·12	0·30	0·16	—	—	39·43	—	0·98	0·95	0·96	1·03
3	56·06	1·05	0·02	0·24	—	1·0	Rem	0·02	1·10, 1·19	1·09	1·12	1·05
4	57·65	1·22	—	0·19	—	0·8	Rem	—	1·14, 1·13	1·08	1·10	1·06
5	57·66	1·23	—	0·19	—	0·8	Rem	—	1·16, 1·14	1·04	1·05	1·04
6	57·64	1·20	—	0·21	—	0·85	Rem	—	1·16, 1·16	1·09	1·09	1·06
7	55·0	1·36	0·02	0·22	—	1·08	Rem	0·02	1·04	1·02	1·03	1·05
8	56·65	1·37	0·02	0·22	—	1·16	Rem	0·02	0·70	0·67	0·69	0·68
9	56·08	0·08	3·92	1·05	0·55	1·87	36·29	—	0·26, 0·26	0·25	0·28	0·24
10	58·4	0·19	—	1·54	1·44	1·27	Rem	—	0·40, 0·41	0·43	0·45	0·40
11	—	1·75	1·01	0·91	—	1·03	33·9	—	0·78	0·79	0·83	0·78

have been obtained down to 0·1% lead in copper base alloys containing manganese and iron.

However, on applying this method directly to the determination of percentages of lead less than 0·1% in these alloys, difficulty was encountered due to interference from iron. It was found that in the presence of iron of the order of several per cent., addition of potassium cyanide caused the formation of prussian blue, and the ferric ions so retained gave a small curve on the high sensitivities of the instrument used for traces of lead. This can be greatly minimised by gently heating the solution until the blue colour disappears, but all efforts to completely remove this interference have been unsuccessful and this method is not recommended for the determination of traces of lead $<0·1\%$ in copper base alloys containing iron. It was also observed during the investigations that the complex ions formed by the manganese with the triethanolamine under the above conditions are responsible for a diffusion current at zero potential with respect to the mercury pool anode.

Absorbers for Carbon and Hydrogen Microdetermination

By A. Lacourt

Centre de Microchemie de L'Université de Bruxelles.

ESTIMATIONS like those of carbon and hydrogen on the micro scale depend on the quantitative absorption and accurate estimation of CO_2 and H_2O. These two essential factors have already been largely discussed and absorbents and absorbers have consequently been designed and adapted according to personal preferences.

In my recent trip to Great Britain these tools interested me, since I have, for quite a long time, been engaged in research in that field. I noticed that ascarite and anhydrone were generally chosen as absorbents for this purpose, and that the Pregl type of absorber was preferred to any other. These absorbers are evidently light in weight even when filled, which is one condition to be fulfilled when working with microbalances. Their shape is simple, which is an advantage in the final wiping process. But the fact that they are constructed with open capillaries at both ends has to be considered from the point of view of accuracy and simplicity.

Such capillaries offer to a certain extent a resistance to the gas flow, therefore, to ensure the safe progress of combustion to CO_2 and H_2O and absorption of these products in the proper absorber, it is necessary to work under suction from a Mariotte Flask, while combusting.

When the combustion is ended and these absorbers are wiped and taken to the balance room, if the temperature there is not exactly that of the laboratory (which it rarely is), the air in these absorbers will either contract or expand. In the first case (that is when the balance room temperature is lower than in the laboratory) contraction will draw more air into the tube and with it CO_2 and H_2O which are not combustion products. In the second case, some of the absorber air will be expelled and with it CO_2 and eventually H_2O accountable to combustion.

These inaccuracies may be as much as 0·1 mg., that is to say from three to five times the blank value. Efforts have been made to minimise these effects and actually good records are given when the wiping and weighing are within 15 minutes after the absorbers have been separated from the combustion apparatus. As this is sometimes a difficult condition to fulfill and moreover, as microchemistry if possible should not depend on empirical processes, it is not surprising that suggestions have been proposed to overcome this defect.

The Friedrich[1] type of absorber and his combustion suggestions are of interest in this connection; I have seen absorbers in Great Britain which were called after Friedrich but which certainly do not represent the latest type of his absorbers. I myself have used his absorbers since 1936 at the Centre de Microchemie de L'Universite de Bruxelles. These were described in 1935 and 1936.[2] The accompanying diagram (Fig. 1) shows that they can be sealed and consequently that the absorbent is protected from any outside CO_2 or H_2O contaminations. This allows their weighing to be done filled with oxygen and at any time after the combustion is finished. They are robust and light even when filled, and can be rested on the microbalance hooks for weighing. No suction with a Mariotte Flask

1 A. Friedrich. *La Pratique de la Microanalyse Quantitative Organique* (Dunod Paris, 1939). pp. 389.
2 *Mikrochem.*, 1935, **19**, 23; *ibid.*, *Molisch Festschrift*, 1936, 118.

is required with them as they have no capillary ends. Their weight when filled does not exceed 6 grams and the Austrian supplier who provided them before the war, sold them in sets of three absorbers of about the same volume and the same weight when filled, so that

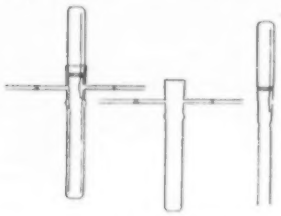


Fig 1.— Friedrich absorber.

they could be balanced on the balance scale by one tare flask (sealed) of the same volume and density. This use of only one tare flask simplifies the weighing process and makes it much quicker as only the increases in weight in each analysis are to be checked using the rider. The first tube is intended to capture H_2O, the second CO_2 and the third is used as a check tube. It should be filled half with anhydrone, half with ascarite, should follow the first two absorbers in all manipulations and should capture nothing. This third tube varies in weight on account of changes in several physical factors affecting weighing between the beginning and the end of the complete analysis. It is presumed that the same weight fluctuation should occur with the other tubes as they are almost alike. So Friedrich proposes to correct by the recorded increase (or decrease) of weight that the check tube underwent in the same time and under the same conditions.

The weight of a check tube in use in one of our researches fluctuated as follows: +58·6; +57·1; +64; +28·5; +31; +15; +14; +17; +9·1; +19; +23; +8; +16; +46.[3]

All these fluctuations happen to be positive in this case, but they may, however, be negative as often as positive.

In the present case, they should be subtracted from the registered increase of weight of each of the two absorbers.

This procedure frees us from empirical manipulations and ensures accurate reliable results and blanks. Having practised this particular technique under Friedrich's directions and afterwards for a long time in my own laboratory, I have taught it to a certain number of my co-workers and to my students. All agree that it has proved successful.

I should like to stress the advantages of this shape of tube and of this technique for the improvement of microchemical techniques.

3 Bull. Soc. Chem. Belg., 1941, **50**, 135.

Polarographic Discussion Panel

A MEETING of the Polarographic Discussion Panel, under the chairmanship of Mr. J. Haslam, M.Sc., F.R.I.C., was held in the Department of Chemist, Lecture Theatre, University College, London, on Friday afternoon, 25th July, when 49 members and visitors were present.

Having welcomed the speakers, Professor J. Heyrovsky and Dr. R. Brdicka, the members of the XIth International Congress of Pure and Applied Chemistry, and other visitors, the chairman called upon Professor Heyrovsky to open the discussion on "New trends of polarographic analysis, differential and oscilloscopic."

The speaker described the construction of the streaming mercury electrode and its use in conjunction with a cathode ray oscillograph. Using a high-frequency time-base, each depolariser present is characterised by a line at a certain potential; if a number of depolariser are present, an "oscillographic spectrum" is obtained. Another circuit arrangement enables an oscillogram having as coördinates rate of change of potential and time to be obtained. This form of oscillogram is suitable for quantitative work. Although not so sensiti e as normal polarography, the oscilloscopic method permits certain determinations (such as of a metal in the presence of an excess of a more noble one) which are otherwise impracticable.

Differential polarography may be performed by using two electrodes of short drop-time dipping into the solution. A "derivative" curve, having change of current with potential and potential as coördinates, may be obtained, and may be used to deduce the half-wave potential and quantity of depolariser present.

Dr. Brdicka then spoke on "The analytical applications of the cystine-and protine reaction in biochemistry and medicine." In ammoniacal cobalt solution, sulphur-containing proteins give rise to catalytic waves, the sulphydryl groups appearing to be the seat of the activity. The wave-height is not proportional to the protein concentration but tends to a limiting value, the shape of the height—concentration curve resembling that of the Langmuir absorption isotherm. Although the catalytic waves are not specific for cystine and cysteine, these two are the active substances usually present in protein hydrolysates, and in many cases may be determined polargraphically at very high dilutions.

In the vigorous discussion which ensued Drs. Benesch, Morris, Page, Stross and Warren, and Messrs Haslam, Milner, Steghart and Stock were among those participating.

Revocation of the Control of Magnesium

THE Minister of Supply has made an Order (The Control of Magnesium (No. 5) (Revocation) Order, 1947), revoking the Control of Magnesium (No. 4) Order, 1942. The effect of the revocation, which comes into force on September 1st, 1947, is to free the acquisition, disposal, and use of all forms of magnesium and magnesium alloys from licencing and to remove price control.

From September 1st, 1947, onwards the Ministry of Supply will cease to sell magnesium direct to consumers. Arrangements have been made for supplies of magnesium to be distributed by F. A. Hughes and Co., Ltd., who will sell pure metal to all United Kingdom consumers without restriction at 1s. 2d. a pound delivered.

Continuous Casting of Alloy Bearing Strip

By T. W. Lamb and E. C. Jeter

ALLOY bearings of the copper-lead type, having a composition of approximately 65% copper, 35% lead, have been used for some considerable time for heavy-duty conditions. The alloy is usually cast against a steel back and quickly cooled through the steel to prevent segregation of the lead. During the war, the Ford Motor Co. decided to develop a connecting rod bearing for its cars and trucks, using the copper lead alloy for the bearing metal, but adapting it to the floating type of bearing, and for this purpose it was necessary to coat both sides of the steel backing with the alloy, making chilling in the ordinary manner impossible.

Early experiments showed that when the applied alloy was permitted to cool from the outside, instead of chilling through the steel, lead segregated at the alloy-steel interface. Nickel, tin or silver, added to the alloy in small percentages, reduced segregation, and after numerous experiments it was found that a silver content of 3–20% would greatly retard segregarion even under conditions imposed by the double facing of bearing metal. The most economical composition was found to be one with 5–6% silver, 35–40% lead, and the balance copper. Tests demonstrated that this alloy, referred to as Silvaloy, was entirely satisfactory. For the steel reinforcement, a low carbon open-hearth hot-rolled 0·075 in. strip is used supplied to the process in coils.

In the manufacture of floating bearings, the coils are placed on racks on the main floor below the gallery on which the alloy is melted. The strip passes over a set of stationary rolls so placed as to permit it to travel upwards to the gallery, then to move in a wide curve to a point directly above the sweat furnace, from hence it straightens out and moves downwards in a straight line into the furnace unit in which the coating is done. The sweat furnace is an ingenious combination of controlled atmosphere, nickel-chromium alloy pot, graphite die or casting mould and cooling jacket in which the entire process of heating the strip, casting the alloy on both sides and chilling the finished material takes place continuously. The strip moves through the furnace at the rate of about 10 in. per min., and the pulling is done by knurled steel wheels, acting on the coated strip just below the cooling jacket. Since the casting is done continuously 24 hours a day, the end of the strip in each coil is welded to the beginning of the next coil and no interruption occurs. The furnace is gas-fired, and is held at 1,150° C., at which temperature the alloy is quite fluid.

The furnace from which the alloy is cast serves only as a sweat furnace, and the alloy must be made up and melted in another unit such as a small induction furnace. The atmosphere maintained in the coating furnace is obtained by cracking propane and is highly reducing, containing approximately 21% carbon monoxide, 32% hydrogen, 45% nitrogen and 2% methane. An alloy containing 0·7–0·8% carbon, 0·6–0·8 manganese, 25–30% chromium, 18–20% nickel and 0·2–0·6% silicon is found satisfactory for the pot which has to withstand severe service conditions continuously at 1,100° C. The graphite dies with an average service life of about 35 hours limit the continuity of the process.

The Silvaloy bearing was developed as a substitute for cadmium bearings due to the shortage of cadmium during the war, and when tested on heavy-duty trucks and military vehicles was found to be superior to the bearings formerly used, having a life two or three times that of the cadmium bearings. Exhaustive tests on the dynamometer stands have shown many runs of more than 40,000 miles with this bearing, and in such runs wear has been quite low. In the case of bearings which have given 50,000 miles of service in trucks, the wear on the wall thickness of the bearing was from approximately 0·00015–0·0015 in., while wear on the diameter of the crankpin was from 0·001–0·002 in.

From *Materials and Methods*, 1946, 23, 1567-1570.

Factors for the Calculation of Hardenability

By I. R. Kramer, S. Siegel and J. G. Brooks

IN 1942, Grossman proposed that the hardenability of a steel might be calculated from its chemical composition by considering the base hardenability associated with its carbon content and grain size and multiplying this base by factors for each element present. Since then several investigators have re-examined the multiplying factors for the individual elements and have found that, while the multiplying principle is valid, some of the individual factor curves developed have been in poor agreement. New data has been made available for manganese, silicon and the other alloying elements, and in order to avoid the possibility that errors in the manganese, silicon, or other curves might influence the iron-factor curve investigation of iron-carbon alloys containing little or no manganese and silicon has been necessary. Other important variables in need of further investigation have been the effect of deoxidation practice on the grain-size correction curves and the effect of stable carbide-forming elements in the depth of hardening.

The steels used to determine such factors, low-alloy steels and low-alloy steel containing nickel, were melted in a basic high frequency induction furnace, split into four parts and appropriate alloy additions made in the furnace before the steels were poured into cast-iron ingot moulds. Two pounds of aluminium per ton were added to the steels that were aluminium killed. The ingots were

From *Metals Technology* 1946, 13, No. 4 and *A.I.M.M.E. Tech. Public.*, No. 2029, pp. 1-28.

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By courtesy of the De Havilland Aircraft Co., Ltd. Front casing for a De Havilland jet propulsion unit (Goblin I). Casting by Sterling Metals Ltd.

homogenised for approximately 12 hours at 1260° C. and forged into 1½ in. rounds, after which they were normalised before machining into Jominy-Boegehold test bars. Test specimens were held at the austenising temperature for 2 hours before quenching by standard methods after which they were wet-ground to a depth sufficient to avoid surface defects.

Hardness impressions were made at first with a diamond hardness testing machine, but later it was found that Rockwell C hardness readings were sufficiently accurate. The Vickers impressions were spaced 0·050 in. apart starting 0.025 in. from the quenched end, while Rockwell C impressions were spaced $\frac{1}{16}$ in. apart. The "half-hardness" was determined from the curve of half-hardness presented by Grossman. Many bars were examined under the microscope for determination of the 50% martensite area until it was found that the two methods gave the same results within ± 10% for most steels. Most of the grain-size determinations were made by a count on photographs taken at appropriate positions on the Jominy specimens after electrolytic polishing and suitable etching.

The results obtained from the various tests showed that grain-size correction was dependent on deoxidation practice and that aluminium-deoxidised steels involved a greater correction than silicon-deoxidised steels. Half-hardness or 50% martensite measurements might be used interchangeably as a criterion for hardenability for Jominy-bar curves that fall off steeply in the vicinity of the 50% martensite zone. The level of the carbon curve was determined on the basis of low-manganese iron-carbon alloys whose ideal critical diameters were determined from quenched rounds and the results of this work were checked by data obtained from quenched rounds and Jominy bars of steels containing iron, carbon, nickel and low residuals. Based on all the data available, the factor curves, for carbon, manganese and silicon were derived so that they formed a balanced system.

The multiplying factor principle proposed by Grossman for the calculation of hardenability from the chemical composition was found to be valid. The principle, however, that alloying elements act independently had to be modified when two or more stable carbide-forming elements were present. For steels containing both chromium and molybdenum it is shown that their overall effect on hardenability was less than would be predicted by the product of their individual factors. This condition only applied when the austenising treatment did not effect a complete solution of carbides. Austenising temperature and time at temperature markedly influenced the effect of stable carbide-forming elements on hardenability. Many small additions of alloying element were not necessarily more effective in increasing hardenability than one large addition. The most effective combination could be determined only by examining the individual factor curves.

Stress Rupture and Creep Tests on Aluminium-Alloy Sheet at Elevated Temperatures

By A. E. Flanigan, L. F. Tedsen and J. E. Dorn

STRESS rupture and creep tests were carried out on five high strength aluminium-alloy sheet materials at temperatures ranging from 35° C. (94° F.) to 190°C. (375° F.). The materials investigated, all in the form of 0·040 in. sheet, were Alclad 24 S–T, 24 S–T 81, 24 S–T 86, 75 –ST and R 301–T (clad). The composition, tensile properties and grain size of these materials are given in Table I. All the alloys were subjected to the standard heat treatment used in their production.

Apparatus was designed to allow the simultaneous testing of 24 specimens in four large furnaces. The shell of each furnace contained a large quantity of a heated liquid through which passed six vertical tubes, 24 in. long, arranged in line on 7 in. centres. Test specimens were heated in the tubes in an air atmosphere, end seals being used to minimise convection of air through the tubes. The furnaces used at 150° and 190° contained boiling glycol-water solutions, while boiling water was used to obtain the 100° C. temperature and water and thermostatic control to maintain specimens at 35° C.

Specimens were loaded in tension in the cross-grain direction, the testing temperatures being 35°, 100°, 150° and 190° C. Stress levels were selected to cause rupture in times ranging from several minutes to 1,000 hours. Test data, including fracture time, elongation at fracture, the complete strain-versus-time curve and creep rate, were obtained by means of extensometers, giving readings equivalent to a change in length of 0·0005 in.. equivalent to a strain of 0·00008 in. per in. in a 6-in. gauge length. Experimental results were shown by means of curves indicating the effects of temperature and stress on fracture time and creep rate. Stress rupture data were also compared with short-time tensile test results obtained at elevated temperatures, and a comparison was made of the materials on the basis of rupture stress at elevated temperatures. The fractures of the various test-specimens were noted and their characteristics defined.

On the basis of rupture stress alone, the materials were ranked in the following order for fracture times up to 1,000° hours :—

35° to 100° C.: 1. 75 S–T. 2. 24 S–T 86, 24 S–T 81, R 301–T and 24 S–T.

150° to 190° C.: 1. 24 S–T 86, 24 S–T 81, 24 S–T 2. R 301–T. 3, 75 S–T.

It was noted, however, that in many applications it might be desired to use other criteria. At the lower temperatures, for instance, 24 S–T might be accorded a lower rank because of its inferior yield stress and at elevated temperatures it might prove less

From *Metals Technology*, 1946, 13, No. 6, and *A.I.M.M.E. Tech. Public.*, 2,033, pp. 1–32.

TABLE I.—COMPOSITION AND PROPERTIES OF MATERIALS TESTED.

Specimen	Composition						Yield Point Tons per sq. in.	Ultimate Stress Tons per sq. in.	Elongation %	Grain Size	
	Cu	Mn	Mg	Si	Cr	Zn				Rolling Direction Grains per mm.	Thickness Direction Grains per mm.
24S–T Alclad ..	4·5	0·6	1·5	—	—	—	21·1	28·1	16·5	19	60
24S–T81 Alclad	4·5	0·6	1·5	—	—	—	27·9	29·5	5·7	22	65
24S–T86 Alclad	4·5	0·6	1·5	—	—	—	28·7	30·0	5·3	17	44
75S–T Alclad ..	1·6	0·2	2·5	—	0·3	5·6	30·1	33·7	10·5	16	54
R301–T (Clad)..	4·5	0·8	0·4	1·0	—	—	26·7	29·5	9·5	48	89

desirable on the basis of corrosion resistance.

At temperatures above 65° C. rupture stresses were generally lower than the values of "yield stresses" determined in comparable short-time tensile stresses and for this reason, such tensile properties as yield stress, ultimate stress, and tangent modulus should be used with caution at the higher temperatures. Under given conditions of temperature and fracture time, the rupture stresses were approximately the same for 24 S–T, 24 S–T 81 and 24 S–T 86. In many cases, the elongation at fracture in stress-rupture tests was less than that obtained in short-time tensile tests under comparable conditions.

The stress-rupture fractures exhibited two characteristic appearances. In the first type the path was perpendicular to the specimen axis and in the second it inclined to the specimen axis at an angle of 60°. The first type was characteristic of 75 S–T at 35° C. but gave way to the second at higher temperatures. This tendency was reversed in the other materials.

Metallurgical Characteristics of Induction-Hardened Steel

By J. W. Poynter

AN investigation was carried out to determine the metallurgical characteristics of steel hardened by induced high-frequency electric currents and to determine if these characteristics differ from those of steel furnace-heated and quenched in the usual way. The effect of various power imputs on the depth and length of the hardened zone produced, on the shape of this hardened zone in a cylindrical specimen, on the metallographic structure, and on the so-called 'super-hardness" were also dealt with.

Test specimens 1 in. dia. were supported vertically inside a coil 1¼ in. internal dia., 2⅝ in. high made from ¼ in. copper tubing and power was supplied by a 30-KW spark gap-type converter. Temperature was measured with a disappearing filament type of optical pyrometer focussed on the specimen. At the conclusion of the heating cycle, the specimen was lifted out of the coil and agitated in the quenching medium, the transfer being made in 3 secs. or less.

A disc ⅜ in. thick for transverse hardness tests and metallographic examination was taken from the centre of the heated zone of each specimen. The top of the specimen was split longitudinally and half of it was ground smooth and etched to show the pattern produced by the hardened zone. The discs were ground flat on both sides and Rockwell C hardness readings obtained $\frac{1}{16}$ in. along a diameter on both sides. On one side the first reading was taken $\frac{1}{16}$ in. from the edge and on the other $\frac{1}{32}$ in. from the edge, thus giving a series of hardness values for every $\frac{1}{32}$ in. from surface to centre. When longitudinal hardness readings were made, about 0·005 in. was ground of two surfaces 180° apart to ensure readings unaffected by the very thin surface oxide layer.

Test specimens were taken from annealed S.A.E. 4340 electric furnace steel containing approximately 0·40% carbon, 0·66% manganese, 0·015% phosphorus, 0·016% sulphur, 1·80% nickel, 0·75% chromium and 0·25% molybdenum. Except for a few specimens induction hardened in the "as-received" condition, all test specimens were normalised at 870° C. for 1 hour and air-cooled. Some of the normalised specimens were tempered at 565° C., some were hardened by oil-quenching from 830° C., and others were spheroidized. The spheroidizing treatment consisted of 16 hours at 705° C., 2½ hours at 775° C., 2 hours at 705° C. and furnace cooling. All specimens were heat-treated in 1 $\frac{1}{16}$ in. or larger size and turned down to 1 in. before furnace hardening.

The results of the various tests showed that the response to heat-treatment, the resulting hardness, and the metallographic structure of the steel were the same whether the specimens were heated in a furnace or by induced high-frequency electric currents. The depth of hardening was increased by increasing the heating times (low power imput) to produce the same surface temperature or by heating to higher surface temperature with the same power imput. The transition between the hardened zone and the unaffected zone is cone-shaped and the hardness of this transition zone is less than that of the hardened zone and in some cases may be less than that of the unaffected metal. In Fig. 1 is shown a cross-sectional hardening diagram under the same operating conditions.

Specimens containing small carbide particles responded more readily to heat-treatment than those in which the carbide particles were larger. There was no evidence, however, that induction hardening resulted in more rapid solution and transformation rates or in the absence of grain coarsening at higher temperatures. It was considered that the effect of frequency on depth of hardening had been over-emphasised since the rate of heat-flow had also a definite effect on the depth of hardening. While evidence obtained regarding "super hardness" was not conclusive, it seemed likely that the increased hardness was related to the presence of internal stresses and not to any difference in the metallurgy of the process.

From *Amer. Soc. for Metals*, 1945, *Preprint* 22, pp. 1–33.

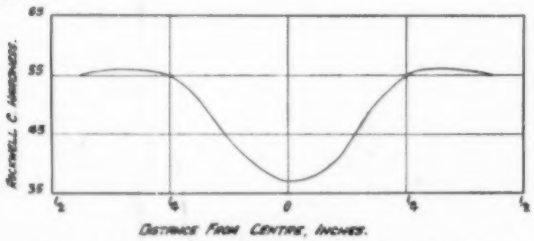

Fig. 1.—Cross sectional hardening diagram under the same operating conditions. Power input, 15 K.W.; surface temperature, 815° C. Specimens normalised and tempered.

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